EVALUATING THREE METHODS THAT CONTRIBUTE TO THE LEARNING OF INORGANIC CHEMICAL NOMENCLATURE

by

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A Dissertation submitted to the
Graduate Faculty of Middle Tennessee State University
in partial fulfillment of the requirements
for the degree Doctor of Arts

June, 2003

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ABSTRACT

EVALUATING THREE METHODS THAT CONTRIBUTE TO THE LEARNING OF INORGANIC CHEMICAL NOMENCLATURE

Joseph Samuel Chimeno

The majority of students about to complete a first year chemistry course have a poor working knowledge of inorganic chemical nomenclature (average quiz scores are less than 60% correct). Usually, the chemical nomenclature topic is not emphasized in a first year chemistry class, and a minimum amount of time is devoted to it. The traditional assignment for chemical nomenclature involves having students work practice problems at the end of the chapter. Students are not very receptive to this approach. The minimal exposure to chemical nomenclature in class along with the ineffective approach of a traditional assignment results in students having a poor working knowledge of chemical nomenclature.

Studies have claimed that students are more receptive to learning when game playing is combined with the learning activity. Therefore two educational games were created to help students develop a working knowledge of inorganic chemical nomenclature: the Rainbow Wheel and Rainbow Matrix.

This study compared the learning of inorganic chemical nomenclature by three different methods; one was the traditional method where students worked problems at

the end of a chapter, and the other two methods used a game format to learn chemical nomenclature.

The statistical analysis of student performance was evaluated with analysis of variance (ANOVA) and t-tests. The analysis revealed that the game format methods were more effective in helping students develop a working knowledge of chemical nomenclature. The ANOVA test indicate that both the Rainbow Wheel and Rainbow Matrix post-assignment mean scores differ significantly from the traditional group's post-assignment mean scores ($p < 0.05$ Middle Tennessee State University (MTSU) data and $p < 0.01$ North Iowa Area Community College (NIACC) data). The t-tests revealed that there were significant differences between the traditional group's post-assignment mean scores and the game format groups' mean scores. The results of this study indicate that students will learn chemical nomenclature more effectively when the subject is presented in a game format. The game format methods used in this study encouraged students to visualize the process of writing chemical formulas correctly, while the act of visualization was not emphasized in the traditional approach.

ACKNOWLEDGEMENTS

A number of people have contributed their time and energy while I prepared this dissertation. Thus, it is my pleasure to thank them for their time and input. First, my appreciation and thanks goes out to the hundreds of students who have contributed their comments and suggestions to me regarding this research. Second, my thanks and gratitude are given to my major professor, Dr. Gary P. Wulfsberg, for all his valuable comments and suggestions. Next, my appreciation and thanks to my committee members, Dr. Amy J. Phelps, Dr. Tammy Melton and Dr. Bob Womack for all their helpful advice and comments. Also, a special thanks is expressed to Dr. Linda A. Wilson for her wisdom and direction. Last, my sincere thanks and appreciation goes out to my wife, Cynthia, for all her patience, understanding, and support. Everyone's help in this endeavor is greatly appreciated.

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CHAPTER 1

INTRODUCTION

A few years ago in one of my introductory chemistry labs, a student came to me and said, "You forgot to place the sulfuric acid solution in the hood." I walked over to the hood and pointed to the bottle of sulfuric acid solution and said, "there it is." The student failed to recognize the bottle of sulfuric acid because the formula $H_2SO_{4(aq)}$ was written on the bottle, but not the name, "sulfuric acid." This incident occurred two weeks before the end of the term. Upon questioning the student further, I realized that this student had failed to develop a basic working knowledge of chemical nomenclature, which includes the relationship between element symbols, ions, formulas, and their names. The activity of converting a name to its individual ions and combining the ions into correct formulas is just one step in the nomenclature operation. Students also need to be able to name the ions and thus be able to name the resulting salt formed from the ions. Figure 1 is a typical example of the mental process of converting a formula to its ions and naming the ions and formula and vice versa. A thorough practice of this process allows students to develop a working knowledge of chemical nomenclature.
It is essential that students in a first year chemistry course be able to convert A→D and D→A, including the intermediate steps of B and C.

After questioning other students in this class, it became evident that almost all the students had a poor command of basic chemical nomenclature. Further inquiry of

A. Formula of Salt: i.e., $FeCl_3$	→ ←	**B.** Formula of Ions: i.e., Fe^{3+} Cl^{1-}	→ ←	**C.** Names of ions: i.e., Fe^{3+} iron(III) Cl^{1-} chloride	→ ←	**D.** Name of salt: i.e., iron(III) chloride

Figure 1. Steps in reasoning the transformation of the Stock name of an inorganic salt to its chemical formula, or vice versa.

other introductory chemistry classes revealed that students were not adequately learning basic chemical nomenclature. When asked why they had not learned the inorganic chemical nomenclature, most of the students said that it was boring and uninteresting to grind out names and formulas. This was a problem: how to make learning inorganic chemical nomenclature fun and exciting, so that students would be motivated to learn it? What could be done to achieve this? What could one do to stimulate first year students' interest in learning inorganic chemical nomenclature? The difficulty was in finding a way to make learning inorganic chemical nomenclature palatable to students.

My students were not alone in their difficulties with chemical nomenclature; troubles of this kind are historic. Chemists in the 18th century also had difficulties with naming compounds, but unlike my students, they did recognize the importance of a systematic nomenclature. According to Oesper (*1*), one cannot describe the ideas and facts of chemistry without having a good working knowledge of nomenclature. He cites Lavoisier:

> In every physical science (chemistry) there are three things to consider, namely: the series of facts that constitute the science, the ideas that recall the facts, and the words that expresses them. The word should give birth to the idea, and the idea should portray the fact: these are three impressions of the same seal. Since it is the words that preserve the ideas and transmit them, it follows that it is impossible to improve the science

> without perfecting its language and no matter how true the facts may be, however correct the idea born from them; they will still transmit only false impressions if there are no exact expressions (words) to convey them.

Lavoisier emphasized the importance of proper language in the field of chemistry. The language of chemistry must convey the ideas and facts in chemistry; without a proper nomenclature, the ideas and facts cannot be conveyed. From this early emphasis on nomenclature and later emphasis by other chemists, the International Union of Pure Applied Chemistry (IUPAC) Stock Method was formulated in 1892. It continues to be revised to the present day (*2-4*).

In Lavoisier's time, there were many different words for the same element and the same compound, thus it was necessary to establish a descriptive, concise and uniform chemical nomenclature. For example, the compound potassium sulfate had five names: *sal polychrestum Glaseri, tartarus vitriolatus, vitriolum potassae, sal de duobus,* and *arcanum duplicatum* (*1*). This created much confusion and hindered communication among chemists of the 18th century.

According to Owens and others (*5*), research indicates that playing in the name of learning really works in the classroom. They give examples of using games in class to teach specific lessons. Games are fun-filled exercises with specific goals in mind. One game that Owens uses is called *the element game*. In this game, students attempt to draw boxes around symbols of elements on a game board. Once an element's symbol is enclosed in a box, the student attempts to name the element. Each enclosed box of symbols is worth 10 points. An enclosed box without a symbol is worth 5 points. The student with the most points at the end of the game wins. Since games have been used to enhance learning, two educational games, the Rainbow Wheel and the Rainbow Matrix were created to help students develop a working knowledge of chemical nomenclature (*6, 7*). The Rainbow Wheel game was developed first and then the Rainbow Matrix was developed later as a computer game, which was patterned after the Rainbow Wheel. The Rainbow Matrix has more features such as the cutouts described below and the versatility of combining more ions into more compounds.

Description of the Rainbow Wheel and the Rainbow Matrix

The Rainbow Wheel chemical nomenclature game consists of two wheels: a cation wheel (Figure 2) and an anion wheel (Figure 3). The cation wheel has 36 common cations around the wheel in a pie-shaped format, and the anion wheel has 36 common anions surrounding its wheel in a pie shaped format. The object of the game is to have the student spin a spindle within each wheel, thus randomly selecting a cation and an anion. Students will spin the spindle selecting ten different cations and ten different anions that are placed on a grid sheet (Figure 4). Students combine the anion and cation into the correct formula in the space provided on a grid sheet. Once the grid is complete, the student will have written the formulas for 100 compounds. On a separate sheet of paper, numbered 1-100, the names of the compounds are written using the Stock Method Nomenclature rules.

The Rainbow Matrix (Figure 5) is the computer version of the Rainbow Wheel. It is not identical to the Rainbow Wheel game, but it is based upon the same concept. Students combine a randomly selected cation and anion from two different matrix charts,

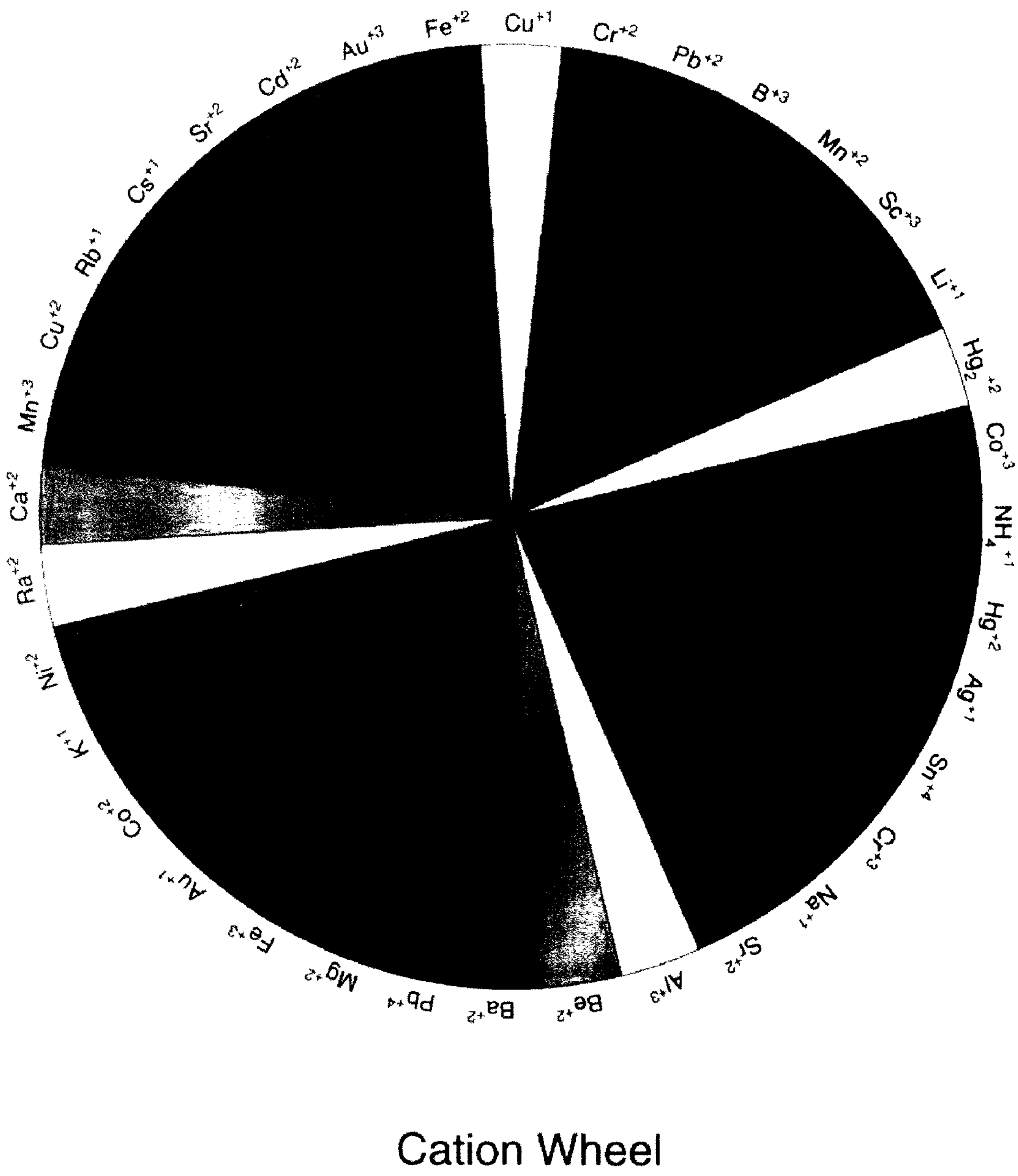

Figure 2. The cation wheel in the Rainbow Wheel chemical nomenclature game.

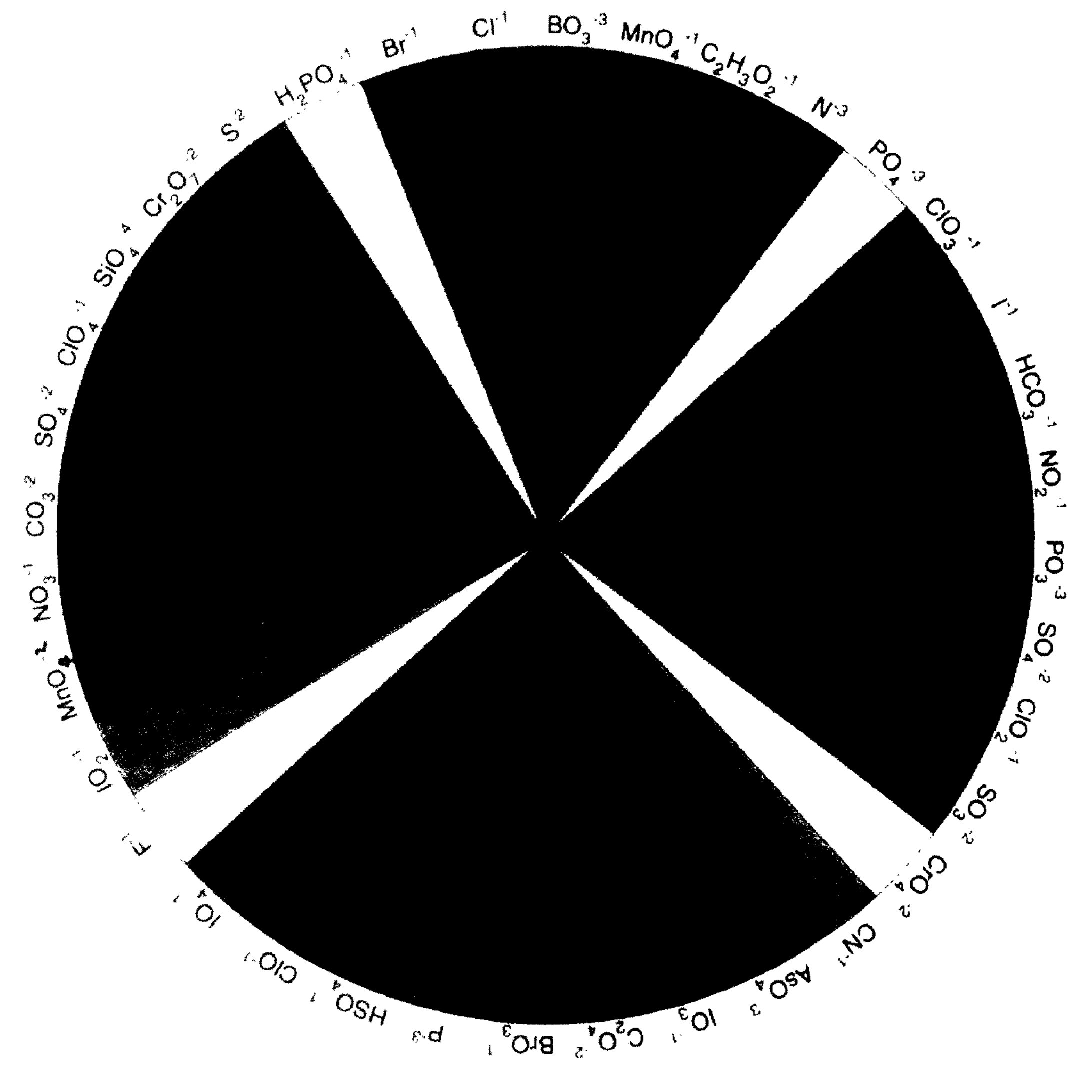

Figure 3. The anion wheel in the Rainbow Wheel chemical nomenclature game.

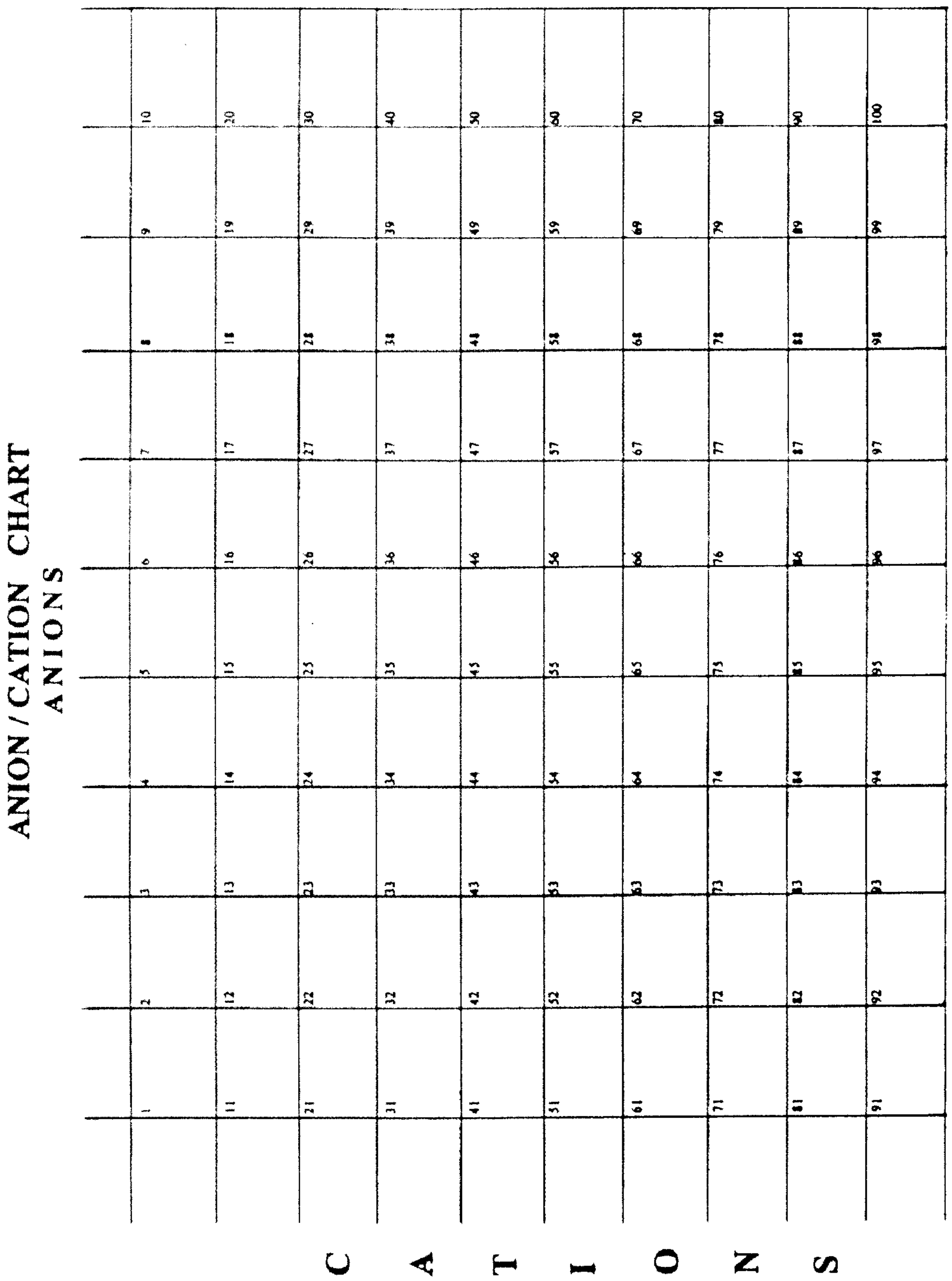

Figure 4. The grid sheet used in the Rainbow Wheel game.

one cation chart and one anion chart. The student types out the correct formula of the cation/anion combination and names the compound. Once a typical exercise is completed, a student will have written the formulas of and named 100 different compounds. When the game first loads, the student is asked to choose between a practice game and a test. The practice game has ion cutouts (Figure 6), which resemble the Pac Man symbols so one can visualize how many ions are required for the correct formula. The test does not provide this clue. The practice session gives the student three times to answer correctly, while the test session gives only one chance to give a correct answer. There are thirty-six different common cations on the cation matrix and thirty-six different anions on the anion matrix. Theoretically, a student could perform 1296 (36^2) different combinations and could write the formula for that many ionic compounds and name them, but the usual assignment only contains 100 possible combinations. Since the Rainbow Wheel game consists of 100 possible combinations of cations and anions, the Rainbow Matrix game was set at 100 combinations of cations and anions as well. Once a student completes his or her assignment, the assignment is graded by the computer, and the results can be e-mailed to the instructor. This allows students to receive immediate feedback from the work just performed. Students have access to the Rainbow Matrix game via the internet (**www.chemgames.com**) at any time of the day.

Tobias and Tomizuka (8) state that the vocabulary of chemistry is a bridge between thinking in words and thinking in the chemistry world. There are over twenty-one million known chemical compounds with an additional 10,000 compounds being added each year. It is impossible for anyone to know all the names of these compounds,

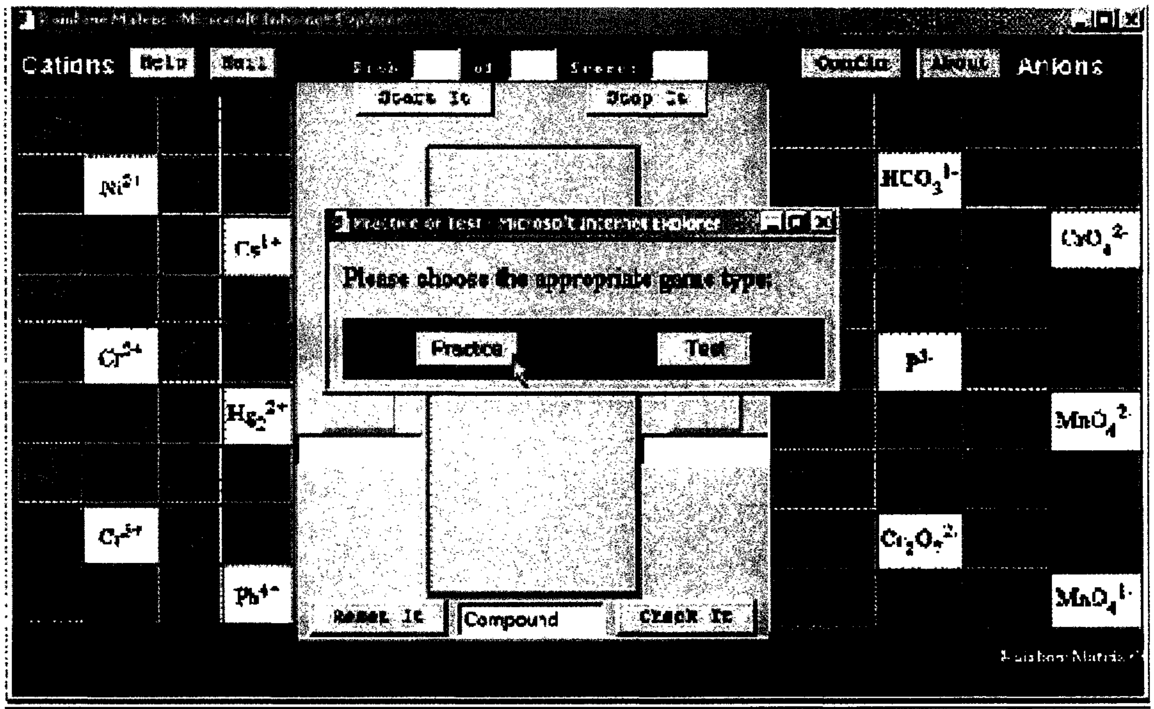

Figure 5. The Rainbow Matrix chemical nomenclature game.

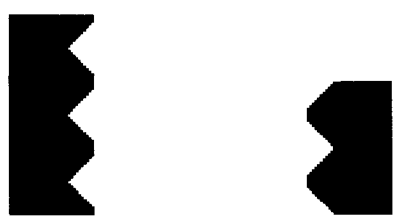

Figure 6. Typical cation and anion cutouts, to represent a +3 charged cation and a –2 charged anion, respectively.

but there are "terms, symbols, process words, and names of chemical quantities that help beginning students learn the language of chemistry" (*8*).

The vocabulary of chemistry includes the terms for sub-microscopic entities such as the atom, molecule, bond, and ion. It also includes the names and formulas of specific substances, which are abbreviated with single- and two-letter symbols. Once a student masters the chemical naming system, he or she will be on the way to becoming "chemically literate" and able to think in a system of "chemical code" (*8*).

Another part of chemical vocabulary involves the process terms. These terms include reaction, oxidation, reduction and quantity terms like molarity, solubility and the mole. By applying these terms to actual problems, students develop an understanding of them. Understanding the terms of a problem will enable students to appreciate the concepts involved (*8*).

Loeffler (*9*) points out the challenge that first year chemistry students have with developing a working knowledge of a wide variety of chemical terms. He emphasizes the importance of knowing chemical nomenclature as part of the chemical language. Loeffler explains that most students think in the concrete world, while we (chemists) are working in the abstract world.

Chemical educators write formulas, which may indicate either a single molecule ("species") or may indicate the behavior of the material in bulk ("substances"). Students often fail to realize the difference (9). For example, students must learn the concept that charges cancel one another when combining cations and anions into a chemical formula. This concept originates in the abstract world of charged species. Writing the formula correctly is expressed in the concrete world of chemical substance. Therefore, it is the substance of a chemical formula. This emphasizes the need for a good command of the chemical language in order to work effectively.

To emphasize the importance of chemical nomenclature, consider the following chemistry problem. A chemistry student mixes 5.0 mL of 0.10 M calcium chloride solution with 10.0 mL of 0.10 M silver nitrate solution in a 50 mL beaker. How many mg of precipitate, if any, is formed and what is it? This problem involves moles, molarity, solubility, chemical reactions, stoichiometry and possibly solubility product constants, but the first step requires an understanding of chemical nomenclature. Initially, the student must be able to write the chemical formulas before writing and balancing the equation.

$$CaCl_{2(aq)} + 2\ AgNO_{3(aq)} \rightarrow Ca(NO_3)_{2(aq)} + 2\ AgCl_{(s)}\downarrow$$

Only after this is done can the student attempt to solve the problem. The chemical topics mentioned above are all important, but without a working knowledge of chemical nomenclature, the student cannot begin to solve the problem. Therefore, it is essential that students have a good working knowledge of chemical nomenclature to successfully complete a first year course.

Chemical nomenclature has become more systematic over the years, but at the same time the amount of chemical knowledge and information has grown immensely. Chemical educators have to make decisions about what topics to focus on given a limited amount of time. Often this leads to a lack of mastery of chemical nomenclature for students *(10-13)*. This study was designed to address this lack of mastery of chemical nomenclature by applying a game format.

Hypothesis

First year chemistry students will develop a better command of inorganic chemical nomenclature by repetitiously combining ions into correct formulas and naming the compounds using a game format. The hypothesis states that there will be a significant difference between the post-assignment quiz mean scores of the students using the traditional method when compared to the post-assignment quiz mean scores of the students using the game format methods.

Traditionally, the process of getting students to learn chemical nomenclature has not been very effective. The students were not interested in learning chemical nomenclature because they found it boring and the instructional delivery was ineffective (*9 -14*). In addition, Brasted (*11*) noted that a minimal amount of class time was devoted to the topic. Typically, students are assigned problems from the end of a chapter that look like this:

> Name each of the following formulas.
> (a) Li_2S (b) $Fe_2(CO_3)_3$ (c) $NaClO$
> (d) $(NH_4)_2SO_3$ (e) $Sr(CN)_2$ (f) $KMnO_4$

or from Brown and LeMay (*15*) write the formulas for the following:

> (a) copper(I) oxide (b) potassium peroxide
> (c) aluminum hydroxide (d) zinc nitrate
> (e) mercury(I) bromide (f) iron(III) carbonate.

When students are working problems like these, they need some motivation to get into the process. A more effective method should be developed which will motivate and stimulate students to enjoy learning chemical nomenclature.

Cassen (*16*) used a BASIC computer program called NOMEC (abbreviation for nomenclature) to enable his first year chemistry students to practice writing formulas and naming compounds. The program can generate over 800 different inorganic compounds. According to Cassen, his students can learn inorganic chemical nomenclature via the computer program better than the traditional classroom lecture. This claim was based upon his experience, but it was not tested in a formal study.

Russell (*18, 19*) reports that game playing may enhance the learning of chemistry by making it more fun and interesting. Retention rates for students increase significantly the more involved the student is in the learning process (*20*).

In 1983, Gardner (*21*) published his seminal book on multiple intelligences (MI). Students are using more of these multiple intelligences when they are playing and learning at the same time. These multiple intelligences are: verbal, visual, interpersonal, logical, rhythmic, body-kinesthetic, and intra-personal activities. When students are playing educational games, they are interacting with one another, thinking, visualizing, talking, kinesthetically moving around, and logically deducing solutions, thus they are utilizing more of their multiple intelligences in the exercise than if they were just writing answers to questions at the end of a chapter (*21*).

The purpose of this research was to compare three methods of practicing nomenclature based on the comparison of mean student achievement on pretest and post-test nomenclature quizzes. The traditional group practiced nomenclature by naming compounds and writing formulas as outlined by homework problems. The Rainbow Wheel group played the Rainbow Wheel game and completed the corresponding grid sheet. The Rainbow Matrix group completed the Rainbow Matrix game. All three groups completed approximately 100 problems. The results were analyzed with the Prism3c statistical analysis software, (Graphpad Software Inc., Los Angeles, CA) which performed the ANOVA and t-test statistical analysis.

Many educators (*6, 18, 19, 22-24*) have used game playing in class as a way to help students develop an interest in the subject matter. These educators claimed that the games were effective in improving student performance, but the data was anecdotal. The actual effectiveness has not been formally tested. The goal of this study is to compare three different methods of practicing nomenclature and to determine statistically any significant difference between the post-assignment quiz mean scores of the three groups.

CHAPTER 2

LITERATURE REVIEW

Nomenclature

A major emphasis was placed upon chemical nomenclature from the late 18th century through the 20th century (*1-4, 26*). De Morveau established inorganic chemical nomenclature with the support of Lavoisier in 1787 (*1*). Initially, this inorganic chemical nomenclature was based upon composition. When the concept of molecular and ionic compounds containing atoms of elements gained acceptance, inorganic chemical nomenclature converted to a stoichiometric basis (*13*). For example, rather than naming a compound ferric chloride, it was later known as iron trichloride and is now known as iron(III) chloride. The process of using Roman numerals in ionic compounds was introduced by Stock in 1938. This became known as the Stock Method, which was adopted by the International Union of Pure Applied Chemistry (IUPAC) (*2*).

Organic and inorganic nomenclature developed quite differently. Inorganic nomenclature was based upon elemental composition whereas organic nomenclature was based upon structure (*13*). Verkade (27) has written at length on organic nomenclature.

The development of x-ray crystal structure analysis allowed inorganic chemistry to catch up to organic chemistry in its understanding of structure. Inorganic nomenclature began to adopt terms from organic nomenclature (*cis, trans, meso*) as well as generate new terms (*fac, mer*), which applied uniquely to coordination compounds. As in organic chemistry, these terms enable inorganic chemist to describe the stereochemistry of molecules (*13*).

Analytical chemists have encountered challenges with nomenclature as well. According to Mellon, writing by analytical chemists was not clear. He pointed out the confusion of terms such as "attestation, azotometry, bomb washing, catalimetric, colaminometric", which have appeared in the analytical sections of *Chemical Abstracts* (*28*). After many committee meetings on nomenclature, the ACS Division of Analytical Chemistry defined specific analytical terms and set standards for nomenclature in 1947.

In 1946, the committee on updating inorganic chemical nomenclature (IUPAC) met to standardize the names of many elements upon which there was no international agreement. For example, the element now known as beryllium was also called glucinium; niobium was also called columbium; tungsten was sometimes called wolfram; and promethium was called illinium. After much debate, the modern names were accepted (*29*).

Eventually, the nomenclature committee ruled that the names of elements should be based upon practical application and common usage. Today, the periodic table is complete with elements now known. The committee does not engage in issues of priority for naming new elements, but require that newly discovered metallic elements have names that end in –ium. Historically, elements such as iron, copper, zinc, silver, tin, gold, mercury, and lead were all named before the –ium ruling went into effect in 1946. Fortunately, the names of these elements are universally accepted and quite engrained in chemical nomenclature, thus they were exempt from the –ium name ruling.

In 1976, Fernelius, Loening and Adams (*26*) pointed out that historians of chemistry have devoted comparatively little attention to nomenclature. Other than the articles by Verkade (*27*), entitled "Historical Studies on the Nomenclature of Organic Chemistry," very little has been published on organic nomenclature. Prior to the 1970's, inorganic chemistry nomenclature was not well represented in the literature either.

During the 1970's, Fernelius and co-workers (*3, 4, 13, 26, 29-30, 32, 33*) and Mellon (*28*) published a number of articles on the importance of inorganic chemical nomenclature. Fernelius quotes from Confucius: "If names are not correct, language will not be in accordance with the truth of things" (*26*). Ideally, all chemical compounds should have a name that allows those with a minimum of training to transform this name to a formula and vice versa. A few chemistry instructors, however, contend that a chemical name is unnecessary, and may be referred to in writing by only its formula (*11*).

Lind (12) emphasizes the importance of establishing a systematic scheme when teaching inorganic nomenclature. He uses a scheme of dividing nomenclature in three parts: cations, anions and compounds. These are listed in a chart that he provides the students (*12*). Lind believes that every student should master basic chemical nomenclature by the end of the first year of chemistry. He reports that his students reacted positively to his scheme and their performance on exams was improved; however, no statistical analysis was performed (*12*).

The rules of nomenclature differ somewhat in various countries. In the US, the name of the most electropositive element (a metal in an ionic compound) is named first, and then the more electronegative element (the non-metal in an ionic compound) is named last. But in France, the opposite is true. For example, NaCl is sodium chloride in the US, while it is ClNa (chlorure de sodium) in French literature. The difference is in the root of the languages. In English and Germanic languages, the electropositive constituent is placed and named first, while the opposite is true in the French and Latin based languages (*30*). The same rule applies with the molecular compounds composed of non-metals, exceptions being ammonia, hydrazine, water, hydroxylamine, phosphine, etc. These are compounds with old traditional names. The rule given by the IUPAC Commission on naming binary compounds between non-metals is this: "That constituent should be placed first which appears earlier in the sequence: Rn, Xe, Kr, B, Si, C, Sb, As, P, N, H, Te, Se, S, At, I, Br, Cl, O, F" (*30*). Sometimes, there is an exception to this rule. For example, the compound, S_4N_4, has a chemical property of a nitride and not that of a sulfide, hence the name is tetrasulfur tetranitride (*30*).

Russian chemists are willing to use formulas to describe complex compounds and thus simplify the naming process. Their name for calomel is kajiomejil, and ammonia is called ammhak. The pragmatic approach of inorganic nomenclature identifies which elements are present in a compound. The forms can be expressed with prefixes or suffixes to describe what form the elements have. In English, when the *chlorine* atom forms an ion, it is known as *chloride* to indicate the formation of an anion. The Russian language uses a similar practice of combining words to identify elements, as well as alteration of the stems to indicate ionic form, but like French, the order of the words is reversed, with the name of the anion being treated as an adjective, which comes before the noun it modifies. Thus, the element HatpИЙ (sodium) combines with xjiop (chlorine) to form xjiophctbiИ HatpИЙ which is literally "chloride of sodium" (*31*).

The multiplying prefixes used in chemical nomenclature are mono, di, tri, tetra, penta, hexa, hepta, octa, nona, deca, undeca, dodeca, etc. The uses of these prefixes include "stoichiometric proportions (i.e., CO_2 for carbon dioxide), extent of substitution (i.e., $SiBr_3H$ tribromosilane) and the number of identical coordinated groups (i.e., $[Co(NH_3)_4 (NO_2)_2]^+$ for tetraamminedinitrito cobalt(III) ion)" (*32*).

Acid salts are named by placing hydrogen in front of the anion name. For example, $NaHSO_4$, is named sodium hydrogen sulfate. When naming double salts, the cations and anions are named alphabetically. $NaMgCl_3$ is named magnesium sodium chloride and $KNH_4HPO_4 \cdot 5\, H_2O$ is named ammonium potassium hydrogen phosphate pentahydrate.

Sometimes chemists are not aware of how descriptive their nomenclature system is. For example, in the field of mineralogy, the mineral lepidolite has two forms: one is lavender and the other is yellow, yet both are called lepidolite. The name does not indicate that the mineral contains lithium, potassium, aluminum, silicon, and oxygen. It is important to chemists that the name of a compound identifies its composition, while geologists are not concerned about this. Geologists are only concerned that lepidolite is a unique mineral (*33*).

Motivation

The internal process of motivation is dependent upon beliefs and expecations. If a student believes that he or she can do a task, the task becomes much easier to perform. Feeling competent empowers a student to do well in any task. Moreover, the greater the sense of competence, the greater the persistence on task and this carries over into future tasks. Motivating a student who fails to successfully complete a task depends on the root cause of the failure. The student who attributes his or her failure to lack of ability requires opportunities to build self-confidence. The student who attributes failure to lack of effort must be motivated to believe that persistence on task will be rewarded with success (*34*).

Dembo (34) and Weiner (*35*) explain that students' perception of their previous work (whether good or bad) affects their performance in their present endeavors. Students who perform well previously are willing to accept future challenges, while students who have not performed well in the past are apprehensive about future challenges. Students need to feel that they have earned their success.

Many first year chemistry students need their instructors to inspire, challenge, and stimulate them. Ericksen stated "Effective learning in the classroom depends on the instructor's ability to maintain the interest that brought students to the course in the first place" (*36*). It is the instructor's responsibility to motivate students in the classroom, and encourage activities that motivate students to want to learn.

Davis recommends the following to help instructors motivate their students (*37*):

- Give frequent, early, positive feedback that supports students' beliefs that they can do well.
- Ensure opportunities for students' success by assigning tasks that are neither too easy nor too difficult.
- Help students find personal meaning and value in the material.
- Create an atmosphere that is open and positive.
- Help students feel that they are valued members of a learning community.
- Work from students' strengths and interest

Ericksen's research (*36*) indicates that "good everyday teaching practices" (*37*) is more effective than attempts to apply motivation theory directly. These good teaching practices include organization and enthusiasm (*36*).

Sass (*38*) describes an effective instructor as one who is enthusiastic and organized. He lists eight items that are important in motivating students. These include being enthusiastic in class, making the material relevant to the students, being prepared to teach the lesson for the day, using understandable explanations, engaging the students, using various teaching modes, developing rapport with students, and using good examples when explaining concepts. The use of these strategies will enhance student motivation and encourage students to put forth more effort (*38*).

In a chemical reaction that forms a precipitate, it is the participating ions that make the reaction occur and not the spectator ions. As in a net ionic equation, students need to become participants and not merely spectators to make things happen. By allowing students to be active participants in learning, students are more apt to be motivated to learn the subject matter. People learn by doing things. Instructors should ask students questions, rather than tell them the answers. They should make their students think about the subject and encourage them to solve problems or predict the results of an experiment. It is a good idea to find out why students are taking the course, how they feel about the subject matter and what their expectations are (*37*). According to Sass, using examples that relate the course material to students' interests or experiences, the students will become more motivated to learn the material. These suggestions will help to motivate students to learn, even if they have no interest in the subject (*38*).

Cairo (*39*) notes that conscientious students "will pursue behaviors that lead to positive consequences and avoid behaviors that lead to negative consequences." But this is counter-intuitive since we all know that some students repeatedly participate in self-destructive behavior. His idea is to increase motivation by "increasing positive outcomes and decreasing negative ones." Cairo believes in rewarding students by meeting their basic needs. His list of five basic needs and wants are love and acceptance, satisfaction from work, approval of others, involvement with a group, and feedback on performance (*39*). The essence of motivation can be expressed in the following statement, "To the degree you give others what they want, they will give you what you want." (*39*)

In addition to the five basic needs of students, Cairo identifies seven personal needs that students have. Fulfilling personal needs is the most consistently proven motivational method known. Seven personal needs that motivate are (*39*)

- *Belonging* – being part of a group provides a sense of comfort, security and partnership;
- *Achievement* – giving life a purpose, and it reinforces self-esteem by demonstrating competence;
- *Advancement* – feeling successful, one needs to continually expand personal and professional skills, knowledge and abilities;
- *Power* – advancing in a career bestows more power or increased authority;
- *Responsibility* – with responsibility comes respect, both for the person given responsibility and for the person who delegates it;
- *Challenge* – feeling challenged to grow mentally and emotionally provides a strong incentive for many students;
- *Recognition* – having others know of your achievements is essential. (Letters, awards, gifts or bonuses are forms of recognition that motivate future actions)

Note that most of the personal needs are emotional in nature. Often providing financial rewards is far less effective than meeting emotional needs. The quality of work performed describes how one feels about oneself.

By observing, asking questions, and listening, an instructor can discover which personal needs are important motivators to individual students. It is noteworthy that more than one researcher has discovered the importance of meeting the personal and basic needs of students (*34-39*).

Motivating college students to learn is one of the greatest challenges that an instructor may encounter. It is necessary for students to learn how to be successful in class. Thayer (*40*) discusses the importance of the first exam, especially in first year courses. It is likely that students receiving poor grades (D's and F's) on their first exam may drop the course when compared to passing students. However, students who receive poor grades on the first exam that do not drop the course may actually improve on the second exam. Using a regression line from the second exam scores to the first exam scores, a more accurate means of measuring the difference between the two scores can be calculated. Using this process, it was observed that students earning A's showed an improvement in their scores. Students who do well on exams usually continue to do so, provided they maintain their good study habits. Giving thorough review sessions helps students to improve on their exams (*40*).

Having positive expectations of students' performance is another way to enhance their motivation to learn. An instructor can openly communicate to the class that he or she has confidence in the abilities of all students to do well in the course, provided they make an effort (*37*).

Mitchell (*41)* says that "Maximum motivation is reached and gratification for accomplishments potentiated when a balance is achieved between our abilities and our responsibilities, when the skills we possess are roughly commensurate with the challenges we face, when our talents are neither underused nor overtaxed."

Once a student becomes a good learner, he or she does not require as much motivation to learn. Also, with enough time and practice, most students will develop competence in a given subject (*42*). These positive learning experiences improve the student's self-image. Therefore, a positive self-image follows successful learning experiences.

Obviously, students who are successful in learning feel better about themselves as learners. In trying to develop a positive self-image without having successful experiences, they are likely to be unsuccessful. Students who are confident in their abilities to learn are those who have experienced success in learning (*35, 37-39, 43*).

Sometimes it is possible to develop intrinsic motivation in students who have very little intrinsic motivation at all. Initially, physical activities such as swimming, golfing, boating, and hiking may be motivated by extrinsic rewards (like being in good physical shape), but later, the same activities can become intrinsically interesting. For example, a student may solve chemistry problems because a reward was offered as an enticement, then the student realizes that he or she is good at solving chemistry problems and discovers that it is fun to solve these problems. Feelings of competence develop and the student realizes that he or she now has an intrinsic interest in solving chemistry problems (*44*).

When students are young and inquisitive, such as they are in elementary school, they are more intrinsically motivated. As they grow older and are "molded" into structural society, many of these students gradually lose their intrinsic interest and are enticed to be motivated by extrinsic rewards (*45*). Educators would do well to keep the fires of motivation burning to maintain students' intrinsic interest in learning. This is a good reason to incorporate educational games in the classroom (*18, 19, 21-24*). Games in the classroom create an atmosphere where students want to learn, thus enhancing intrinsic interest in learning.

Literature on Teaching with Games and Play

The implementation of learning strategies is essential to student's motivation at all levels of education. According to Skinner (*46*),

> A good program of instruction guarantees a great deal of successful action. Students do not need to have a natural interest in what they are doing, and subject matters do not need to be dressed up to attract attention. No one really cares whether Pac-Man gobbles up all those little spots on the screen. Indeed, as soon as the screen is cleared, the player covers it again with little spots to be gobbled up. What is reinforcing is *successful play* (emphasis added), and in a well-designed instructional program students gobble up their assignments.

Skinner's point is that students are more than willing to learn if they are provided effective programming with sufficient reinforcement.

Lundy (*47*) recommends the use of non-competitive games to be used in educational settings. In these games, all the participants play for the joy of the game and the lesson to be learned. To the extent that non-competitive games are geared toward cognitive learning and challenge, all of the active participants experience a sense of achievement by learning new strategies. These games eliminate the negative emotional consequences of low self-confidence and of feeling defeated that are experienced in competitive games. Non-competitive games build self-confidence in the participant and allow one to feel victorious by mastering a particular task. These games can develop intrinsic interest in the activity, and the participant can generate a desire to learn the task at hand (*47*). It is possible to motivate students with games by getting their attention, getting them involved in discussing and explaining concepts and working with hands on exercises. Therefore, the use of educational games in the class or the lab is a good way to motivate students to learn, since it involves all of these strategies (*6, 7, 18, 19, 21-25, 47*).

Sometimes society stifles our growth by trying to get us to conform to the "normal" way of doing things. Many times, we hear our colleagues say that this is the way we have always done it, why change it? (This is the resistance that one encounters when attempting to introduce new ideas). The art of real teaching and learning is lost in the race to cover a maximum amount of material in a limited amount of time. Play and other enjoyable learning activities cannot be rationalized away. The integration of play with learning needs to be reunited in the higher-level classrooms as it is in the elementary years. Students that play together, learn together. Thus, the idea of having fun while learning is still a viable concept. More instructors are realizing the importance of allowing students to have fun while learning (*6, 18, 19, 22-25, 41, 47*).

Gardner (*48*) states that "schools attempt to cover too much material and that superficial understandings (or non-understandings) are the inevitable result." It would be a better idea to invest quality time on important concepts, fresh ideas, and necessary questions, thus allowing the students to become more familiar with the essence of the subject. Gardner suggests that important topics can be approached in a variety of ways that prove "pedagogically appropriate for the topic at hand" (*48*). Some of the ways to approach a topic includes story-telling, formal debate, artistic exploration, hands-on experiment, game playing, or computer simulation. These approaches should be encouraged since they require the students to be more actively engaged in the subject. By using multiple approaches in teaching a topic, the seven multiple intelligences of verbal, visual, interpersonal, logical, rhythmic, body-kinesthetic, and intra-personal are used, and thus increase the students' chances of grasping the material (*48*).

The following examples of teaching with games are actual exercises performed in class. Although the instructors report an improvement in student performance, the actual increase in performance and achievement was not tested. These exercises were done in class for fun and enjoyment and as a way to create more interest in the subject matter. The students did indicate that they had a greater interest in the subject after playing the games, but these responses are anecdotal (*6, 18, 19, 22-25*).

One of the first educational games in chemistry was introduced in 1935 (*25*). The game was called *chemical lotto*, which is similar to the game bingo. The game consists of a list of one hundred chemical formulas having corresponding chemical, mineralogical, historical, or trade names. The names are written on small pieces of cardboard and placed in a container to be drawn from. Assorted formulas of the compounds are written on cards similar to bingo cards. Someone draws the names from the container. Students match the names to the correct formula, and the first player to get five formulas across the card wins the game. The five formulas must be horizontal, vertical or diagonal on the card (*25*).

Another chemical educational game that was introduced in 1935 was known as *chemical dice* (*25*). Symbols of metals are placed on the faces of each of three wooden cubes, each face having one symbol. Symbols for non-metals or non-metallic ions are placed on faces of three other cubes. (Sub-numerals are used to indicate different valence values). The six dice are rolled a number of times and the player attempts to match up top faces to obtain correct formulas. Since the player is matching a metal symbol (cation) with a non-metal symbol (anion), the formulas will represent ionic compounds (*25*).

Russell and others (*18, 19, 22-25*) have used a variety of games to teach chemical concepts. Two of Russell's favorite games are the *Old Prof* card game (*18*) and the *CheMoVEr* board game (*19*) (pronounced "chem mover"). The *Old Prof* card game is a cross between *Old Maid* and *Go Fish* (*18*). The deck of cards consists of 24 pairs of cards containing the symbols and names of the most common elements and one *Old Prof* card, for a total of 49 cards. The object of the game is to match symbol with name, making a pair. Once a pair is made, the player lays it down until all cards are played. It is necessary for the students to know the symbols by name to successfully play the game. The game can be played with 3 to 9 players. Russell's students play these games during laboratory times at the beginning of each term. She reports that these games increased student interest in the subject and made the course more enjoyable (*18*).

The *CheMoVEr* board game is a cross between Sorry and Parcheesi. Two to four can play at a time, and the players move their pieces around a board by answering chemical questions correctly. The board contains a starting square for each player, which is connected to a central finish area by a series of squares. Each square contains the symbol of an element. The player draws a card from the top of the deck and answers the question or identifies a formula. Correct answers are on the back of the card with the number of squares the player can move with a correct answer. The players move counterclockwise around the board until they come to the square with the same color as their game piece, then they can move toward the finish area via the squares. The topics covered in this game include chemical nomenclature (writing formulas, naming compounds, and identifying polyatomic ions), balancing equations, and predicting products (*19*).

The questions have short answers to allow the game to go along quickly. The students actually learn from each other rather than hearing information from the instructor. The fun of playing a game motivates the students to learn the material, and it is reported that sometimes the students became so involved in the game that it was difficult to get them to stop and go to their next class (*19*).

Many educators, including Deavor and Keck (*22, 49*) use the *Chemical Jeopardy* game with their students. A number of chemical topics are chosen per game. As in the *Jeopardy* game on TV, chemical answers are listed under the topics. Each answer has a certain point value. The participating student must make up a correct question that fits an answer to receive the points. Students play this game to introduce a review exercise. The points awarded can be treated as quiz points. The game has been used in both the introductory and general chemistry courses. The instructors reported that their students' interest and participation in class discussion has increased since introducing the *Chemical Jeopardy* game (*22, 49*).

Denny and others (*50*) have used a *Riddle Game* to encourage students to learn chemistry. It is very popular with students, and a typical riddle looks like this:

Pull them all and take in charge
Cool so many, spoil the sky
Hang in chain which DuPont like
Near Noble, try to tell my Name

The student attempts to solve the riddle by identifying the element being described. The answer to the above riddle is fluorine. It is near the noble gases and has the highest electronegativity. Fluorine forms strong covalent bonds with carbon and results in the toughest polymers, Nafion and Teflon, which DuPont makes. Fluorine is in Freon, which is a coolant in refrigerators, but Freon damages the ozone layer in the atmosphere, hence it spoils the sky. Riddles such as these are found on exams or as homework problems. It was said to be a great way to cause students to think about chemistry (*50*).

Crute (*24*) uses chemistry bingo to teach both inorganic and organic chemical nomenclature. Bingo cards are produced with chemical formulas written in the boxes. As the instructor calls out the names of the compounds, students check off the formulas. Once someone completes a row horizontally, vertically, or diagonally, he or she shouts "bingo" (*24*). This game is similar to the *chemical lotto* game described earlier (*25*).

Dreyfuss (*51*) developed a novel idea to get his students involved in learning chemistry. He had his students literally paint the periodic table on his car. The students used nine different colors placed randomly in 92 squares covering the entire car. Although the project did not duplicate the periodic table exactly, the elements were arranged in a close approximation of the periodic chart. The project involved the effort of 63 high school chemistry students. Dreyfuss called the vehicle his *Periodicar*, but the students simply called it "The Car" and played a game at school similar to *Where's Waldo*? The idea was to locate the car as Dreyfuss drove around town. Dreyfuss reported that the students enjoyed the activity, and he said that it increased their knowledge of the various elements on the periodic table. The students had fun discussing the periodic table and sharing their new knowledge with the local community. The activity of discussing the periodic table was performed all year long and not just for the two-week discussion when covered in class (*51*).

There are a number of computer-based games that are used to teach chemical topics. Some of these games and their topics are:

Chemgames.com (chemical nomenclature) (*7*);

Chemical Pursuit (facts about general chemistry) (*52*);

Periodic Table Games (formula and nomenclature) (*53*);

Practice with Chemical Symbols, Formulas, and Equations (formulas, nomenclature and equations) (*52*);

Chemistry Checkers (chemical properties) (*52*);

Hungry Frog Chemistry, Chemistry I: Ion Charges & Formulae (charges of ions and formula) (*54*);

Chemaze (common reactions) (*55*);

Chemical Dominos (reactions and products) (*56*);

Chemical Dungeons (ionic reactions) (*52*); and the

Concentration Quiz (solubility) (*52*).

Russell reports favorable results from the use of these games (*17-19*). With the growing popularity of these games, there is a strong interest in using games to teach chemistry. The feedback indicates that students' interest in chemistry has increased and many instructors report that more of their students said they enjoyed taking chemistry (*18, 19*). Since all of these reports of effectiveness are anecdotal, there is a need to investigate the effectiveness of educational games in helping students develop a working knowledge of various chemical topics.

Literature on Computer Assisted Instruction

Sands (*57*) used a computer program to help his students develop a working knowledge of organic chemical nomenclature. The program allowed his students to name various organic compounds and recognize a preparation (synthesis) of the compound. The compounds include the acyclic, mono-functional, six-carbon aliphatics, and a few cyclics. Classes include the alkanes, alkenes, alkynes, alkyl halides, alcohols, ethers, aldehydes, ketones, primary amines, nitro compounds, acids, acid salts, acid halides, un-substituted amides, esters, and acid anhydrides. A few other mono-functional aliphatic compounds are included, mostly six-carbon compounds. The student chooses a class of compounds and types in one of the numbers given for that class. The computer displays the structure and asks for its name. The student types in the correct name, then the computer prompts the student to give the type of reaction for the preparation of the compound. If the student answers correctly, another compound may be chosen. If the student answers any question incorrectly, the computer gives four chances to answer correctly before counting it wrong. This computer program is popular with students, but there is no statistical evidence to measure its effectiveness (*57*).

Mullin and Courtney (*23*) developed a computer program called *Find & Circle* to teach their students chemical nomenclature. The program "constructs a letter matrix" where names of compounds can be found. The instructor can input a list of words of compounds to be found in the matrix. Upon giving the students a list of formulas, the object of the game is to find the name of the formula in the letter matrix. Students eventually solve a matrix puzzle by locating the names of compounds within the letter matrix. The game can be re-programmed to allow the students to find the formulas within a matrix after being given the names of various compounds. The instructor can also insert other names in the matrix to see if the students recognize the correct names (*23*). Although Mullin and Courtney report that this game is popular with their students, no statistical analysis was conducted.

Cassen (*16*) used a computer program known as NOMEC to help his students develop a working knowledge of chemical nomenclature. The program can produce over 800 different combinations; the students must match up the names with the formulas. The students are furnished with handouts, which include the instructions and rules of nomenclature. Cassen reports that his students learned inorganic nomenclature as well, or better with this program than they do in his traditional classroom discussion and homework assignments, but this claim was not supported (*16*).

The advantage of this program is that it enables students to practice chemical nomenclature outside of class and receive immediate feedback on their progress. Cassen's program covers the nomenclature of oxo-acids, binary salts and salts of oxo-acids. After naming compounds and writing formulas, the student's responses are analyzed and acknowledged. If incorrect, the computer allows the student to try again. After each correct response, the student is given the option to write formulas, name compounds, or terminate the program (*16*).

According to Clark (*58*), instructional methods are defined as the "provision of cognitive processes or strategies that are necessary for learning but which students can not or will not provide for themselves." Educational games provide students the opportunity to use cognitive processes (learning with a game) that students cannot provide for themselves. The game format adds that extra element that is missing in traditional assignments of working problems at the end of a chapter. Nevertheless, Clark maintains that the use of media does not enhance the learning process (*58*).

A number of chemistry instructors (*6, 18, 19, 22-24, 49-51*) have reported using various games to teach chemical concepts. All of these instructors reported that their students were receptive to using the games, and the students indicated that the games made the subject matter fun and interactive. The instructors also noted an improvement in the students' exam scores after using the games (*6, 16, 49*). It is interesting to note that with all the published literature on using games to foster learning in the study of chemistry, not one of these reported statistical analysis to evaluate the actual effectiveness of game playing.

The problems with and the importance of chemical nomenclature for success in first year chemistry courses are apparent in the literature. The tedious nature of learning nomenclature and students' lack of understanding about the importance of such knowledge lead to low motivation. The implementation of games to assist in the learning of nomenclature might enhance motivation by increasing the interest in the activity. Other attempts to use games as teaching aids in chemistry indicate positive results but most results were anecdotal rather than tested claims. This study was designed to investigate in a formal way the claim that games enhance the learning of chemical nomenclature.

CHAPTER 3

METHODOLOGY

This study tested the effectiveness of using games to assist in the learning of chemical nomenclature. The control group was the group that participated in a traditional homework assignment. This control group was compared to the Rainbow Wheel and Rainbow Matrix groups each of which played a game to learn nomenclature.
Each group was instructed on chemical nomenclature prior to the pre-assignment quiz. After taking the pre-assignment quiz, each group worked with their assigned practice activity (traditional, Rainbow Wheel, and Rainbow Matrix). Upon completing their practice sessions, each group took a post-assignment quiz. Students were allowed to use the periodic table and a list of common ions while they took the pre- and post-assignment quizzes. A list of common ions, the pre-assignment quiz, post-assignment quiz and questionnaire are included in the Appendix as A, B, C and D, respectively.

The Rainbow Wheel and Rainbow Matrix groups were compared to the traditional group to determine whether the Wheel and Matrix practice methods were more or less effective than traditional homework in helping students develop a working knowledge of inorganic chemical nomenclature. The study was carried out in two different settings, which produced two data sets. The two different data sets are described below, one collected at North Iowa Area Community College (NIACC) and one collected at Middle Tennessee State University (MTSU).

NIACC Sample

Three different first year chemistry classes participated in a chemical nomenclature study at North Iowa Area Community College in Mason City, Iowa. The student enrollment at the college for the 2001-2002 academic year was 3033, and about 200 students took chemistry courses per term. The average student age at NIACC was 22. The study involved students registered in CHEM 140, a one-semester introductory chemistry course. This one semester course was designed for nursing students, nutrition majors, and other science-related students. Each class had about 30 students enrolled; two classes met on Monday, Wednesday, and Friday (MWF) and one class met on Tuesday and Thursday (TuTh). Each class performed the practice activity (traditional homework, Rainbow Wheel and Rainbow Matrix) in the laboratory on Friday of the same week and then took the post-assignment quiz on a lecture day of the following week. For the MWF classes, the post-assignment quiz was taken on Wednesday and for the TuTh classes it was taken on Thursday. All three classes were taught by the researcher. The results of the assignments and post-assignment quiz were part of the students' grade for the course.

Procedure

All three classes were instructed in the Stock Method nomenclature rules (Appendix E) and examples were worked in class. One class was designated the control group, where nomenclature was taught using traditional practice methods such as assigning problems from the end of the chapter (*59*). Another class was designated as the Rainbow Wheel group and worked with the Rainbow Wheel chemical nomenclature game. The third class was designated as the Rainbow Matrix group and worked with the Rainbow Matrix chemical nomenclature game. Each class assignment was graded and returned to the students the next class meeting to provide feedback. Three hours of class time were devoted to naming compounds, writing formulas, and teaching the nomenclature rules. Lists of common ions were provided (Appendix A) for use during the pre- and post- assignment quiz along with copies of the periodic table. Each class took a twenty-minute pre-assignment quiz (Appendix B) after the three-hour introduction to chemical nomenclature. During the respective lab periods (2.5 hours), classes completed their specific assignments, and the instructor was available to answer questions. After completing the assignments, each class took the same post-assignment quiz (Appendix C).

The assignment for the traditional group of students at NIACC consisted of answering problems 5.13 through 5.36 at the end of chapter five in the Ebbing text (*59*). These problems had multiple parts making up approximately 100 exercises all together. Thirty-one of the exercises involved converting the formula of ions into the formula of a salt (B→ A in Figure 1); thirty-eight exercises involved converting formulas of salts into their names (A→ D); twenty-four of the exercises involved converting the name of a salt into its formula (D→ A); fourteen exercises involved converting the formula of a salt into its individual ions (A→ B); and three questions involved converting the name of ions into the formula of a salt (C→ A).

In contrast, the one hundred practice exercises for the Rainbow Wheel and Rainbow Matrix assignments each gave the formulas of the ions and asked, first for the only types of conversions that the game format students were asked to perform.

The pre-assignment and post-assignment quizzes for all groups consisted of ten questions that gave the names of the salts and asked for the formulas of the salts (D→A), while the other ten questions gave the formulas of the salts and asked for the names (A→D). Only the traditional group of students had practice questions of both types.

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MTSU Sample

This sample was conducted at Middle Tennessee State University (MTSU) in Murfreesboro, Tennessee. It is the second largest public higher education institution in Tennessee with six colleges: Graduate Studies, Basic and Applied Sciences, Business, Mass Communication, Education, and Liberal Arts. MTSU is a regional comprehensive university with an enrollment of 21,163 students during the 2001-2002 academic year. The average student age was 24 (*60*). The sample included students registered for the CHEM 1110 course (the first semester of a two-semester general chemistry sequence), which met on MWF. This course is designed for pre-professional majors and other science majors for instruction in basic chemical principles.

Procedure

A first semester chemistry class of 60 students was divided into three groups. An instructor other than the researcher was the instructor of record for the class. The same pre-assignment quiz and post-assignment quiz was administered to all three groups at the same times, respectively. The class containing all three groups was instructed in inorganic chemical nomenclature by the researcher. The Stock Method rules (Appendix E) were discussed with examples worked in class for a one-hour class period. Lists of common ions were provided (Appendix A) along with copies of the periodic table for use during the twenty-minute pre-assignment and post-assignment quizzes. After being introduced to the nomenclature rules and working examples together in class, the pre-assignment quiz (Appendix B) was given to the students. The pre-assignment quiz scores served as a baseline for each group. The whole class received instruction in the use of the Pac-Man symbols for combining the cations and anions. The students were assigned code numbers so that matched pair t-tests could be performed on the quiz results while maintaining student anonymity. Each groups' assignment was completed in the lab period following the lecture on nomenclature. It was graded and returned to the students at the next class meeting to provide feedback. The time allotted for each assignment was the same for each group (2.5 hours). Upon completing their lab assignments on Thursday, each group took the same post-assignment quiz seven days later on Wednesday.

The assignment for the traditional group of students at MTSU consisted of answering problems 2.45 through 2.62 at the end of chapter two in the Brown and LeMay text (*15*). Many of these problems had multiple parts, and to make a total of 100 exercises, eighteen others were added. These exercises were quite varied in their nature: twenty-eight gave the ion formula and asked the students to write the formulas of the salts (B→A); four gave the names of the ions and asked students to write the formulas of the ions (C→ B); four gave the formulas of the ions and asked for the names (B→ C); eighteen gave the formulas of the ions and asked for the names of the salts (B→ D); twenty gave the formulas of the salts and asked for the names of the salts (A→ D);

twenty-one gave the names of the salts and asked for the formulas (D→ A); twenty-four gave other miscellaneous tasks.

The Rainbow Wheel and Rainbow Matrix exercises were the same as the ones performed in the NIACC data set: (B→ A) and (B→ D) type conversions. All three groups took the same pre- and post-assignment quizzes as described in the NIACC data.

The students in the Rainbow Matrix group had certain difficulties to overcome before they could perform the Matrix nomenclature game. First, they needed to be familiar with computer technology, and know how to play the game. It requires a certain amount of time to learn how to play the Rainbow Matrix game. Second, the number of computers available in the lab limited the number of students who could actually participate in the assignment. Third, the accessibility to the computers presented a problem to the physically disabled students. One student could not access the computer lab because he was in a large wheelchair. Special accommodations were made for him, and he was able to access a computer and play the Rainbow Matrix game.

Questionnaire

Each participating student in the MTSU sample answered a four-question questionnaire (Appendix D). Students were asked questions on what they liked most about the way they were taught chemical nomenclature. They were asked to evaluate the method they used to learn chemical nomenclature. Students were asked to recommend improvements, if any, in teaching chemical nomenclature. In addition, the questionnaire asked the students whether they believed they had attained a certain level of mastery of chemical nomenclature by participating in the study. This question was asked to see whether the students thought that they had learned chemical nomenclature from their respective assignments.

The constant comparison technique (*61*) for data analysis was used to determine the emergent themes from the questionnaire data. The data was read and re-read in an effort to identify emergent categories that would serve as a summary of the students' thoughts.

Statistical Analysis

Both analysis of variance and t-tests were used to analyze the data. When the t-ratio (t-test) is greater than 1.96, one can reject the null hypothesis that the mean values for each group are the same (*62*). When the t-ratio level is 1.96 or greater, the null hypothesis is rejected, but only 95% of the cases would actually have different mean values. To put it another way, at the 95% confidence level one could expect an error in judgment to occur only one out of twenty times, or 5% of the time. This can be expressed as $p = 0.05$, where p represents probability of rejecting a null hypothesis when it is true. Educators usually use the 95% confidence level to compare samples involving t-tests. When t-ratios are greater than 1.96, one can reject the null hypothesis and state that the values are significantly different at the 95% confidence level (*62*).

According to statistical research, a result is considered statistically significant when you would reject the null hypothesis when it was true less than 5% of the time. This is expressed as working at the 95% confidence level when $p = 0.05$ or less (*62*). Determination of statistical significance in this study was set at the 95% confidence level.

The t-ratio (t-test) is calculated by dividing the mean difference between two groups (X_1-X_2) by the standard error of the difference between means symbolized as s_{x1-x2}. The equation is: $t = X_1 - X_2 / s_{x1-x2}$ (*62*).

ANOVA is an acronym for analysis of variance. Analysis of variance is a well-defined procedure for partitioning the total variation of data collected into its component parts. The Friedman's test (F ratio) is often used to measure the variance among sample groups. A simple equation for the F ratio, $F = s^2_1/s^2_2$, calculates the ratio of one sample's variance to another sample's variance (*63*).

In statistical analysis, the more the F ratio deviates from one, the greater the significant difference between groups. The actual F ratio for sample groups is the ratio of the variance between groups (s^2_{bg}) and the pooled within groups variance estimate (s^2_w); therefore, the F ratio = s^2_{bg}/s^2_w (*64*).

In regard to the NIACC sample, ANOVA and unpaired t-tests were conducted. For the MTSU sample, ANOVA and matched-pair t-tests were conducted on this data. The t-tests between pre- and post-assignment quiz mean scores for the NIACC sample were not paired while in the MTSU sample they were paired for each student. The results for both of these are in the next chapter. By rejecting the null hypothesis, one can say the academic groups are significantly different, which implies that there is a difference between the performances of the two groups (*64*).

CHAPTER 4

RESULTS AND DISCUSSION

An analysis of the two data sets (NIACC sample and MTSU sample) revealed that the game format methods do have a positive effect upon students' post-assignment scores. The null hypothesis stated that there would be no difference between the traditional method post-assignment mean scores and the game format methods (Rainbow Wheel and Rainbow Matrix) post-assignment mean scores. The statistical difference was set at the 95% confidence level where $p = 0.05$ or less. The two data sets were analyzed separately, and then compared to see if there were any similarities or differences.

NIACC Sample Analysis

The statistical analysis for this data set is presented in Table 1 and Figure 7. The pre-assignment quiz mean scores for the NIACC sample ranged from $50.1 \pm 24.3\%$ to $57.5 \pm 23.4\%$ correct. There were no significant differences between these mean scores ($p = 0.44$) according to the ANOVA. The post-assignment quiz mean scores for the three groups ranged from $72.4 \pm 2.9\%$ to $92.4 \pm 1.5\%$ correct. The ANOVA test for the three groups indicated that there was a significant difference between the post-assignment quiz mean scores ($p < 0.01$). T-test analyses were performed comparing the traditional class post-assignment quiz mean scores and the Rainbow Wheel post-assignment quiz mean scores. The t-test indicated a significant difference at the 95% confidence level ($p < 0.01$). A t-test was performed between the traditional class post-assignment quiz mean scores and the Rainbow Matrix post-assignment quiz mean scores. There was a significant difference at the 95% confidence level ($p < 0.01$). A t-test was performed between the Rainbow Wheel group and the Rainbow Matrix group. The difference between the Rainbow Wheel and Rainbow Matrix post-assignment mean scores was significant at the 95% confidence level ($p = 0.025$).

Table 1. THE UNPAIRED T-TESTS BETWEEN PRE- AND POST ASSIGNMENT QUIZ MEAN SCORES FOR NIACC CLASSES.

	Pre-quiz	Post-quiz	% increase
1. Traditional Group	57.5 ± 23.4%	72.4 ± 2.9%	14.9% ↑
2. Rainbow Wheel Gr.	50.1 ± 24.3%	87.7 ± 1.8%	37.6% ↑
3. Rainbow Matrix Gr.	55.5 ± 21.3%	92.4 ± 1.5%	36.9% ↑

MTSU Sample Analysis

The hypothesis for this data set was evaluated in terms of the pre- and post-assignment quiz data summarized in Table 2 and Figure 8. The pre-assignment quiz mean scores ranged between 31.5 ± 31.2% and 41.4 ± 20.1% correct for the three groups. The ANOVA comparison showed no significant difference between the three groups' pre-assignment quiz mean scores ($p = 0.581$) (Table 2). There was a significant difference between the traditional method and both game format methods for the post-assignment quiz mean scores ($p = 0.022$), according to ANOVA.

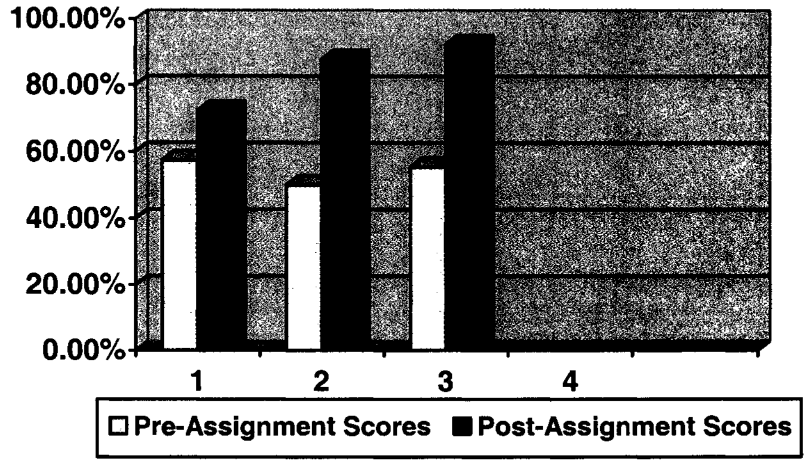

Figure 7. Pre and post-assignment quiz mean scores for NIACC classes.

The study was designed to look at three groups within one class, but there were twelve students who missed the lab assignment completely and inadvertently formed a fourth group. This group of students attended the class on the nomenclature rules, and they completed both the pre- and post-assignment quizzes. The fourth group's pre-assignment scores had a mean of 23.8 ± 23.7% correct which was not significantly different from their post-assignment scores ($p = 0.18$). The increase in pre-assignment to post-assignment quiz mean scores for the fourth group was 12.7% and was not significantly different from the pre-assignment quiz mean score. The fourth group of students' post-assignment quiz mean score of 36.5 ± 12.7% correct is within the range of the other three groups' pre-assignment scores (31.5% to 41.4% correct). This establishes a baseline that a typical group of first year chemistry students will score less than 60% correct on the pre-assignment quiz and do not improve significantly on the post-assignment quiz, provided they do not complete a focused assignment in chemical nomenclature. This emphasizes the point that first year chemistry students generally have a weak background in chemical nomenclature and are in need of a focused nomenclature assignment. The statistics on this fourth group of students are included in Table 2 and in Figure 8.

Table 2. THE MATCHED PAIR T-TESTS BETWEEN PRE- AND POST-ASSIGNMENT QUIZ MEAN SCORES FOR MTSU CLASS.

	Pre-quiz	Post-quiz	% increase
1. Traditional Group	39.1 ± 31.2%	65.6 ± 30.6%	26.5% ↑
2. Rainbow Wheel Group	31.5 ± 17.4%	84.2 ± 11.5%	52.7% ↑
3. Rainbow Matrix Group	41.4 ± 20.1%	87.3 ± 12.1%	45.9% ↑
4. Non-participating Group	23.8 ± 23.7%	36.5 ± 21.4%	12.7% ↑

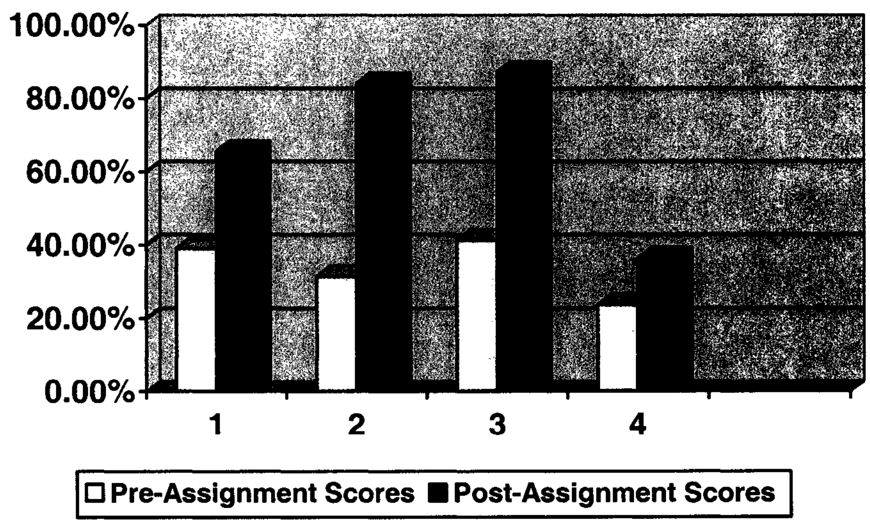

Figure 8. A comparison of the four groups pre- and post-assignment quiz mean scores conducted at MTSU.

The post-assignment quiz mean scores for the four groups ranged from 36.5 ± 21.4% to 87.3 ± 12.1% correct (Table 2). The ANOVA test performed on these mean scores showed a significant difference compared to each other at the 95% confidence level ($p = 0.022$) (Figure 8). Both the Rainbow Wheel and Rainbow Matrix groups showed a significant difference from the traditional group and non-participating group's post-assignment quiz mean scores. T-test analysis was performed on the traditional class post-assignment quiz mean scores and the Rainbow Wheel post-assignment quiz mean scores. The t-tests showed a significant difference at the 95% confidence level ($p = 0.048$). T-test analysis was performed on the traditional class post-assignment quiz mean scores and the Rainbow Matrix post-assignment quiz mean scores. This t-test also showed a significant difference at the 95% confidence level ($p = 0.036$). In this data set, the post assignment quiz mean scores between the Rainbow Wheel and the Rainbow Matrix groups showed no significant difference ($p = 0.724$) (Table 2).

Matched pair t-tests were performed on each student within their respective group's pre-assignment and post-assignment quiz scores (Table 2). The matched pair t-test on 16 students in the traditional group showed an average increase of 26.5% from pre- to post-assignment quiz mean scores, while the matched pair t-test for 13 students in the Rainbow Wheel group showed an average increase of 52.7% for its pre- and post-assignment quiz mean scores and 11 students in the Rainbow Matrix group showed an average increase of 45.9% for its scores. All three groups showed a significant difference in their paired t-test results. The differences were significant at the 95% confidence level in all three cases ($p < 0.01$). There was a much greater improvement between the pre-assignment and post-assignment quiz mean scores for both the Rainbow

Wheel and the Rainbow Matrix groups as compared to the increased improvement in the pre- and post-assignment quiz mean scores for the traditional group.

An additional data source was the first exam for the course. There was one page that was devoted to chemical nomenclature, which was written by the instructor. The exam was given the day after the lab assignment on chemical nomenclature and before the post-assignment quiz. Students were asked to combine certain cations with certain anions into the correct formula (B→C in Figure 1). They were asked to name specific formulas (A→D) and write the correct formula for certain compounds (D→A). Students wrote their code and group number at the top of this page for identification. Each group's average on the nomenclature section was calculated and analyzed. The Rainbow Matrix group had the highest mean on the nomenclature section (87.1 ± 8.7%) and the Rainbow Wheel group had the second highest mean (78.5 ± 18.8%) while the traditional group had the next to lowest mean (63.3 ± 31.0%). The non-participating group had the lowest mean of 56.5 ± 24.9%. The mean scores on the nomenclature section of the exam were analyzed using ANOVA and the statistical analysis revealed that the Rainbow Matrix group's mean score was significantly different from the two lowest groups' mean scores at the 95% confidence level ($p = 0.032$). T-test analysis was performed between the Rainbow Wheel group's mean score (nomenclature section on the exam) and the traditional group's mean score (nomenclature section on the exam), and they were not significantly different ($p = 0.133$). The t-test performed between the Rainbow Matrix group's mean score and the traditional group's mean score (nomenclature section on the exam) were significantly different at the 95% confidence level ($p = 0.021$). There was no significant difference between the Rainbow Matrix and Rainbow Wheel groups' mean scores for the nomenclature section on the exam ($p = 0.180$). Although the Rainbow Matrix group's mean score on the exam section on nomenclature was the only group with a significant difference from the other two groups (traditional and non-participating groups), the difference in scores would be significant to the students from a practical perspective. For example, the 87.1% average for the Rainbow Matrix group would be equivalent to a B+, while the Rainbow Wheel group's average of 78.5% would be equivalent to a C+, the traditional group's average of 63.3% would be equivalent to a D, and the fourth group's average of 56.5% would be equivalent to an F.

The instructor for the MTSU class (*65*), commented that his "students performed better on chemical nomenclature on their first exam than any class that I have ever had previously." The emphasis that was placed on nomenclature, due to this research, may have accounted for the improvement in the students' test scores on the first exam on the nomenclature section.

Comparison of NIACC Sample to MTSU Sample

The ANOVA test reveals that both the Rainbow Wheel and the Rainbow Matrix post-assignment quiz mean scores differ significantly from the traditional group post-assignment mean scores for both sets of data ($p = 0.022$ MTSU study and $p < 0.01$ NIACC study).

For the NIACC study, the Rainbow Wheel scores increased by 37.6% (pre- to post-assignment quiz) while the Rainbow Matrix scores increased by 36.9%. The traditional class had an increase of 14.9% from pre- to post-assignment scores. For the

MTSU study, the Rainbow Wheel scores increased by 52.7% (pre- to post-assignment quiz) while the Rainbow Matrix scores increased by 45.9%. The traditional class had an increase of 26.5% from pre- to post-assignment scores. The fourth group (non-participants) had an increase of 12.7%. The above increases from pre- to post-assignment quizzes were all statistically significant, except for the fourth group.

The NIACC classes spent three hours of class time on nomenclature rules and examples, while the MTSU class spent one hour of class time on nomenclature rules and examples. Also, the work performed by the NIACC students counted as part of their grade for the course, while the work performed by the MTSU students did not count toward their grade. This may have caused a difference in the two sets of pre- and post-assignment quiz mean scores. For the NIACC study, the pre-assignment quiz mean scores ranged from 50.1 ± 24.3% to 57.5 ± 23.4%, while the MTSU pre-assignment quiz mean scores ranged from 23.8 ± 23.7% to 41.4 ± 20.1%. Class days are the same length of time in both cases, about one hour per class. The researcher taught the NIACC classes exclusively, while another instructor taught the MTSU class except for the nomenclature section.

There were ten questions on the post-assignment quiz that asked the students to write the formula of a salt from its name (D→ A). Only the traditional group students had practice questions such as these in their assignment. One might hypothesize that the traditional group of students would show the most success on these types of questions, but the contrary was observed. The game format students (Groups II and III) scored higher on their post-assignment quizzes than the traditional group (Group I) in both data sets. This supports the effectiveness of game playing in enhancing learning.

The statistical results from these two data sets support one another and indicate that these two educational games were effective in helping students develop a working knowledge of inorganic chemical nomenclature. This was the proposed hypothesis, and the data support the proposition that students are more receptive to learning when a game format is incorporated into the learning process. This theory was based upon the psychology of learning, which states that the more engaged a student is in a task, the more likely he or she will learn from the task. The data from both of these studies support this theory (5, *18, 19, 34, 35, 37-39*).

Questionnaire Responses

After the collection of data at NIACC, anecdotal feedback from the students indicated that the students enjoyed the game format, and it made the nomenclature lesson into a fun activity. The NIACC students said that the visualization experience with the games helped them to understand how the ions fit together. In an effort to formally collect such data, the MTSU students were given a questionnaire upon completion of the post-assignment quiz (Appendix D). The response rate from the questionnaire was 40%.

The constant comparison technique was used to find the emergent themes from the questionnaire data (*61*). Emergent themes that are found throughout the students' responses are considered to be important. From the students' responses, five major themes were identified: the role of visualization, the role of the instructor, the role of practice, the role of game playing, and the importance of chemical nomenclature.

Emergent Themes

Visualization was important to students because it helped them to see how the ions fit together in forming the ionic formula. Students valued the fact that they could take the notes on ions and put them into visual form and see what was just spoken and written in class. The importance of being able to grab the ion cutouts and link them together was really emphasized by the Rainbow Matrix group, and it helped them to write correct formulas.

Group III (Rainbow Matrix) Student Responses:

"The matrix game helped me to visually see how the compounds are formed."

"The Rainbow Matrix game really helped me to visually understand and interact with naming compounds which helped me learn the material."

"The computer really helped me to visually understand."

Group II (Rainbow Wheel) Student Response:

"The wheel helped me to see how everything is being put together."

Group I (Traditional) Student Responses:

"I would suggest making some kind of game or memorization exercise out of it. I think this would make it more interesting and easier to see how it all fits together."

Even the Group I students whose assignment did not include any visual cues valued the role of visualization. Pictorial language (visualization) is also important in the chemical education literature as described by various chemical educators. For example, the effectiveness of computer animations on students' conceptual understanding of the particulate nature of matter has been emphasized by Sanger and others (*66-71*).

Another example of the importance of visualization in student learning is found within the research on the effects of molecular models on students' conceptual understanding of the particulate nature of matter (*71-75*). The chemical education community has spent a great deal of time investigating teaching methods that include particulate pictures, computer animations, and molecular models (*66-75*). Thus, visualization is one of the important themes that chemical educators use in teaching various chemical concepts, in addition to being important to the students in this study.

The **role of the instructor**, who was the researcher in this case, was another important theme identified by the students. The students liked that the instructor explained details thoroughly to them. They appreciated that the instructor was available to answer questions and work examples for them by showing how the ions paired up during the laboratory time. The role of the instructor was especially important to the Group I students because the instructor was the main source of information for them.

Group I (Traditional) Student Responses:

"It was explained simply and my questions were happily answered with a reason why."

"I liked the helpfulness of the instructor. Everything was taught very clearly and in a way that I could understand it."

"I liked that everything was explained in detail; you weren't left to guess or assume anything."

"It was made as simple as possible. I was taught the charges for the different cations and how to name them."

Group II (Rainbow Wheel) Student Responses:

"The instructor was very helpful in explaining how to play the Wheel game."

"Complete instructions on using the game were provided by the instructor, and he was willing to answer my questions about writing the formulas."

Group III (Rainbow Matrix) Student Responses:

"The instructor helped us understand how to set-up the Rainbow Matrix game and worked a few examples for us."

"The instructor helped me work the computer game."

These comments support Ericksen's statement earlier that "effective learning in the classroom depends on the instructor's ability to maintain the interest that brought students to the course in the first place" (*36*). Moreover Davis states that "Whatever level of motivation your students bring to the classroom will be transformed for better or worse, by what happens in that classroom" (*37*). "Good everyday teaching practices" (*37*), such as explaining things in detail and working thorough examples in class, will do more to bolster student motivation to learn than any special effort directed at motivation will do (*36*). The role of the instructor is very important to students especially when the instructor is the main source of information. This helps to explain the overall level of satisfaction expressed by all three groups in this data set.

All three groups emphasized the **role of practice**. The students actually wanted more examples to be worked in class and assigned as homework. The act of repeating the combinations over and over emphasized the importance of practice to the students. Generally, the students thought that practice helped them to remember the names of ions and formulas.

Group I (Traditional) Student Responses:

"I like the forced repetition."

"Doing the problems over and over was a little repetitive, but in the long run, helped drill it into my head. Maybe narrow down the number of problems?"

"I would recommend a whole lot more practice, i.e. homework problems and quizzes."

"The method used was effective for me."

"Again, practice helped tremendously."

"I didn't like doing the pre/post quiz because I felt like I hadn't had enough practice since high school and it was a little discouraging."

Group II (Rainbow Wheel) Student Responses:

"The repetition helped a lot, actually."

"Maybe if there was more variety to pairing and naming them. For example, use 20 cations to pair with 5 anions to make 100 or vice versa. It gives more practice."

Group III (Rainbow Matrix) Student Responses:

"Took too long, but if 100 is the right # (sic), then it will be fine."

"By repeating the combinations over and over, it really drove the point home and helped me see just how to do chemical nomenclature."

The role of practice is definitely an effective learning tool when it comes to remembering specific steps involved in nomenclature. Skinner *(46)* reminds us that students learn by repeating certain processes over and over until the skill becomes second nature. Thinking continuously (practice) allows students to learn concepts. Underwood (76) says that we, as learners, have been told that we must practice, practice, practice to master a task. He describes how practice can be made more effective. Research has shown that "distributed practice" among frequent and short periods is more effective than a smaller number of sessions of "massed practice". If a student wants to remember the names of compounds without error, he or she should practice for many short sessions, and repeatedly say the names. When students stay up all night cramming for an exam, this is an example of massed practice. Although this practice method may be effective in remembering a large amount of basic information in a short time, it is a poor method of remembering complex information. This type of practice does not lead to lasting learning since students have forgotten the crammed information after a few days (*76*). Other theorists (*77-80*) suggest the term "rehearsal" for learning that depends upon repeated processes. The more an item is rehearsed, the greater the probability that it will be retained. The game format methods require the students to rehearse (practice) the formula writing and naming processes over and over again until the process is engrained in their memories.

The **role of game playing** was important to the students in Group II and III where the assignment was based upon playing a game. They expressed ideas indicating that it was fun and made the lesson more interactive. Game playing allowed the students to participate in the process of learning the material rather than just writing answers to problems. Even students not involved in the game format methods saw the potential value of game playing in enhancing learning.

Group I (Traditional) Student Response:

"I would suggest making some kind of game or memorization exercise out of it (the assignment). I think this would make it more interesting and easier to learn."

Group III (Rainbow Matrix) Student Responses:

"I wish that more of chemistry was taught using a computer game."

"I liked the computer game."

"After working with the Matrix, I now have a much better understanding of chemical nomenclature. When I was in high school, I never really understood how the formulas were to be written and named, but now it is all clear to me."

"Other students should try using this computer game."

"I really think the computer room (matrix) should be used for a while along with the lecture. It's really excellent."

Group II (Rainbow Wheel) Student Responses:

"Playing the game (wheel) was fun and helped me to practice naming everything. The Rainbow Wheel was effective because it was presented like a fun game and it kept my attention better."

"I liked the wheel of nomenclature we did in lab."

"It was interactive instead of just reading about it in the book."

"The color wheel and chart made it easy to learn."

"I felt like we were too old to play a game to learn."

(Even though the one student thought that she was too old to play a game, she later said it helped her learn the material).

These comments support the literature results about the effectiveness of game playing with learning. As Russell (*18*) stated, games increase student interest in the subject and make the course more enjoyable. Exercises that are fun and interactive are more likely to be pursued by students than those that are not (*18*).

The **importance of chemical nomenclature** was considered to be a valuable theme to students. Many of the students enjoyed the research because of the emphasis placed on chemical nomenclature when communicating formulas in the language of chemistry.

Group I (Traditional) Student Responses:

"I like the emphasis placed upon its importance."

"I liked the lab research because I feel like I got the most that I've ever gotten out of nomenclature in lab, and I understand the importance of nomenclature after the lab."

Group II (Rainbow Wheel) Student Responses:

"I already had some knowledge of nomenclature, but this study has helped to improve it and clarify some things to me."

"I now understand the transition metal's charges (how you know which one to use and how to name them). Also, the naming of the compounds is easier for me. I had not known before about adding the -ide to chlorine, sulfur, etc."

"I have never really worked with nomenclature, so after this I have a much greater understanding. Not mastery, but much more than before."

Group III (Rainbow Matrix) Student Responses:

"I now have a much better understanding of chemical nomenclature and its importance."

"I am now aware of the importance of chemical nomenclature when communicating with other students in chemistry."

Other chemical educators (*1-4, 9-14, 16, 23, 24*) have described the importance of chemical nomenclature in the language of chemistry. Lavoisier (*1*) reminds us that the words that express the facts of chemistry "give birth to the idea, and the idea should portray the fact". Students often see chemical nomenclature as a useless exercise, but the students involved in this research seemed to value it and begin to see the overall importance of being able to communicate effectively in chemistry.

Many of these students had a positive experience working with the various practice methods of chemical nomenclature. The comments about using a game format are encouraging. There were students in the traditional group who were positive about the experience even though they were not exposed to the more effective methods used by the students in Group II and Group III. This was a testament to the role of the instructor in motivation.

In summary, students in Group II and III stated that the visual aspects of the Rainbow Wheel and Rainbow Matrix games were helpful because it allowed them to see how the ions actually come together. These two groups stated that the game format was fun and interactive. They also mentioned the importance of the instructor and that more practice was important to them. The game format was one of the features that gave them that extra edge to do better on their assignments *(5, 6, 18, 19, 22-24)*. The Group I students emphasized the role of the instructor and practice as being important to them. These students as a group did not emphasize visualization or game playing as being important to them. Although, one of the students in the traditional group (Group I) suggested that the nomenclature exercise at the end of the chapter should be put into a game format of some kind, thus making the assignment more interesting.

According to the literature, (*66-75*) visualization (pictorial language) is a very effective teaching tool when it comes to developing new skills and grasping concepts. The students confirmed this assertion by their comments. Also, the use of practice is another important learning technique when it comes to developing skills such as writing chemical formulas and naming them. Again, this was supported by the students' comments. The use of game playing in learning has been supported by both the literature and the results of this study (both quantitative and qualitative). The importance of the instructor as an element in student motivation was demonstrated in this study based on the students' comments and was emphasized by Ericksen and Davis (*36, 37*).

All of the emergent themes (role of visualization, role of the instructor, role of practice, role of game playing in learning and the importance of chemical nomenclature) have been documented in this study. It is amazing how students can improve their performance in class by simply adjusting their attitude to want to learn. The success of learning with games justifies further experimentation in this field. If the utilization of educational games in the classroom can improve students' performance when it comes to learning certain skills, it would prudent to pursue further research in this area.

CHAPTER 5

CONCLUSIONS AND IMPLICATIONS

The purpose of this research was to determine the effectiveness of game playing as an approach to enhance learning. This study compared two game format methods to the traditional method of practicing chemical nomenclature in two different settings by comparing student achievement in learning chemical nomenclature. The statistical results indicate that the game format methods were more effective in helping students develop a working knowledge of chemical nomenclature than the traditional method. While the study was designed to control as many variables as possible, there was a notable difference in the type of exercises the traditional group performed. The exercise of converting the name of a salt to its formula (D→A), which was on the post-assignment quiz, was included in the problems completed by the traditional group, but not by the game format groups. The game exercises were designed to have students write the correct formulas from specific cation and anion combinations and name the resulting formulas. In spite of the practice advantage, the game format students out-performed the traditional students by achieving higher scores on the post-assignment quiz in both data sets.

This research supports claims made by Owens and others *(5, 18, 19, 22-24)* that playing in the name of learning really works. Many educators (*16-24*) have experimented with the idea that students would be more receptive to learning if they enjoyed the experience. That is why they incorporated game playing exercises in their regular class activities. The instructors reported that their students enjoyed performing the games and noticed an improvement in exam scores, but there was no formal data to support this claim. The data from this study provided documented support for the claim that game playing does enhance learning.

The old adage "practice makes perfect" is supported by the results of the statistical analysis when one considers Group IV in the MTSU data set. This was the group of non-participants who did not perform any practice session at all. There was no significant improvement in their pre- and post-assignment quiz scores. The skill of correctly naming compounds and writing formulas from combinations of ions can be developed by practice over short periods of time. The importance of practice was shown by the significant increase from pre- to post-assignment quiz scores in the three different groups (traditional, Rainbow Wheel and Rainbow Matrix) that performed their lab assignments. Practice does make a significant difference in students' scores and is valued by the students. In the questionnaire responses, students asked for more homework to be assigned and for more examples to be worked in class indicating a desire for more practice. Some students valued the "forced repetition" that was required of them to complete the lab assignments. These comments emphasized the importance of practice to the students (*20, 46, 76-80*).

In the NIACC sample, the Rainbow Matrix post-assignment quizzes mean scores were significantly different from the Rainbow Wheel post-assignment quiz mean scores. A t-test showed a difference at the 95% confidence level ($p = 0.025$), but in the MTSU sample, there was no significant difference between the Rainbow Matrix and the

Rainbow Wheel groups' post-assignment quiz mean scores ($p = 0.724$). The students in the NIACC sample had more time to use the Rainbow Matrix game than the MTSU students. The NIACC students had access to the Rainbow Matrix game prior to doing their post-assignment quiz, and it was introduced to them in their first class on chemical nomenclature and before their lab assignment. The NIACC students experienced lecture on nomenclature for three class days, while the MTSU students had only one day of class on nomenclature. The increased practice time afforded the NIACC students, combined with the fact that the NIACC students were being graded for their work, and the MTSU students were not being graded, might account for differences in their quiz scores.

When the Rainbow Matrix post-assignment quiz scores are significantly different from the Rainbow Wheel post-assignment quiz scores, the use of the computer (media) and/or the use of the cutout symbols might account for this difference. This result may question Clark's statement that "learning through media does not enhance the learning process" (*58*). A separate study controlling this variable would be required to address this issue.

The unique feature of the cutouts of ions in the Rainbow Matrix format helped students visualize two ions (cations and anions) coming together in the correct combination. This visualization feature may also account for the significant difference between the Rainbow Matrix results and the other two methods' results in the NIACC data. In addition to being highly valued by students, the use of visualization (*66-75*) techniques is effective in helping students learn various skills and concepts and is one of the multiple intelligences (*21*).

The game format was more effective in helping students grasp nomenclature, and it did require the students to work. The idea is to get the learner in the right frame of mind to put forth sufficient energy to do this work. The game format makes the learning experience a more interactive and fun exercise, thus the student is more willing to perform the task at hand. The idea of including game playing in learning requires the instructor to be more creative and innovative in presenting new topics. It takes more work on the instructor's part, but the results are worth it.

Implications

The success of the game format has led the researcher to consider the option of expanding its use in the curriculum. The topic, chemical nomenclature with educational games, could be the foundation for a new approach to general chemistry. Imagine a wagon wheel with the hub being chemical nomenclature and various chemical topics extending from this hub to the wheel itself (Figure 9). The hub of the wheel could be the topic of chemical nomenclature and the spokes connecting the hub to the wheel itself could be other chemical topics. For example, the topic of aqueous solubility (a spoke in the wheel) could be introduced after discussing chemical nomenclature. Students could be assigned the task of separating the ionic compounds that they have named into categories of those that are water-soluble and those that are not. Later, this topic could be expanded to include K_{sp} and ion solubility.

Another topic stemming from chemical nomenclature could be chemical reactions. Students could write equations that result in the compounds they named from their earlier exercise and reduce these to net ionic reactions, which is another topic.

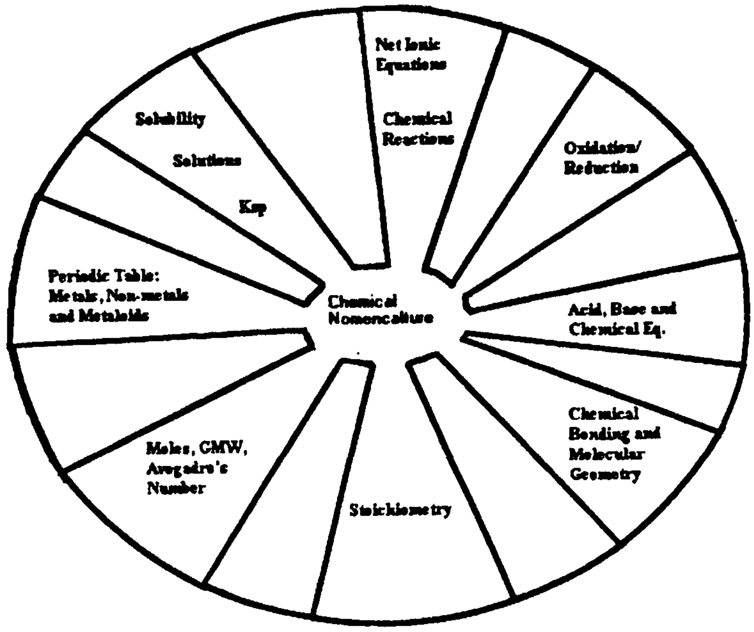

Figure 9. Various chemical topics connected to chemical nomenclature.

Oxidation-reduction reactions involve net ionic half-reactions, and the charges on the individual cations and anions in half reactions would be an appropriate introduction to oxidation-reduction. Oxidation-reduction could easily lead to the activity series topic.

How these ions and their parent elements are arranged on the periodic table could definitely come from chemical nomenclature. This would relate to the topic of metals, non-metals and metalloids. Students could be asked to distinguish between ionic compounds and molecular compounds from their experience in chemical nomenclature. Many topics covered in a general or introductory chemistry class could be linked to chemical nomenclature, since it is such an integral part of the language of chemistry.

Once the student completed the circle of the wheel through the connecting spokes, he or she would have covered most of the major topics in a first year chemistry class, and thus complete the course.

To keep the student learning in a productive and active manner, the incorporation of games with each of these topics could provide the necessary drive. This is one way to develop an intrinsic interest in a subject by providing extrinsic rewards, like game playing and having fun. This is similar to the activities described earlier about swimming, golfing, boating, and hiking being motivated by extrinsic rewards; after a while, the same activities could become intrinsically interesting. As long as the extrinsic rewards are given in moderation and are warranted, this will prevent the "over-justification effect" (*44*) from occurring. The "over-justification effect" occurs when too many extrinsic rewards are given which overshadow the intrinsic interest in performing a task. The experience of applying games to introduce chemical topics would enable students to see a first year chemistry course from a whole new perspective.

Games are useful in teaching certain skills, but have many limitations when trying to teach concepts. What type of games could one possibly play to introduce different topics encountered in a general chemistry course? The answer requires creative thought and imagination. The *Jeopardy* format (*22, 49*) has been used for chemical review, and it could be used to introduce a variety of chemical topics.

Another popular mental exercise that could be used as an educational game would be the old TV program *Concentration* (*52*). A series of matching terms or topics are hidden on a marquee. The object of the game would be to match the appropriate term or topic after seeing them throughout the game, and to solve the rebus behind the matched pairs. This game would use the logical-reasoning capability of students and require them to identify chemical terms and topics at the same time. This exercise could be developed into another educational computer game, which could be used for review.

This study revealed the effectiveness that games have upon students' ability to learn chemical nomenclature. The idea of learning with play is not new. Formal learning with play is first experienced in pre-school and elementary school. What this study supported is that learning with play can be effective in the discipline of chemistry in a higher educational setting. To learn something new is a grand experience and instructors would do well to apply their creative energy in ways that will generate novel ways to present their subject. With more effective practicing techniques, students can be empowered to become better learners.

Two new approaches to practicing chemical nomenclature were tested in two different learning environments, and the data supported the effectiveness of the Rainbow Wheel and the Rainbow Matrix over the traditional homework practice. It would be interesting to measure the longitudinal effects of learning with play. For example, students could be tested after several months to see how well they retained their knowledge of chemical nomenclature.

The outcomes of this study support the effectiveness of learning with play, which is one creative approach to encourage students to learn. Educators might consider reflecting upon ways to improve the teaching/learning exchange that occurs between student and teacher and make their discipline more attractive to prospective students.

Supplemental information is appended as appendices F through K, which includes complete questionnaire responses, letter to students requesting consent, consent form, approval letter from MTSU, approval letter from NIACC, and the approval letter from the institutional review board.

APPENDIX A

LIST OF COMMON IONS

A List of Some Common Ions

Cations: (positively charged ions)

Lithium Li^{+1} Sodium Na^{+1} Potassium K^{+1} Rubidium Rb^{+1} Cesium Cs^{+1}
Hydrogen H^{+1} Hydronium H_3O^{+1} Ammonium NH_4^{+1} Beryllium Be^{+2}
Magnesium Mg^{+2} Calcium Ca^{+2} Strontium Sr^{+2} Barium Ba^{+2} Radium Ra^{+2}
Chromium(II) Cr^{+2} Chromium(III) Cr^{+3} Manganese(II) Mn^{+2} Manganese(III) Mn^{+3}
Iron(II) Fe^{+2} Iron(III) Fe^{+3} Cobalt(II) Co^{+2} Cobalt(III) Co^{+3} Nickel(II) Ni^{+2}
Nickel(III) Ni^{+3} Copper(I) Cu^{+} Copper(II) Cu^{+2} Silver Ag^{+} Gold(I) Au^{+1}
Gold(III) Au^{+3} Zinc Zn^{+2} Cadmium Cd^{+2} Mercury(I) Hg_2^{+2} Mercury(II) Hg^{+2}
Aluminum Al^{+3} Tin(II) Sn^{+2} Tin(IV) Sn^{+4} Lead(II) Pb^{+2} Lead(IV) Pb^{+4}

Anions: (negatively charged ions)

Borate BO_3^{-3} Cyanide CN^{-1} Carbide C^{-4} Cyanate OCN^{-1} Carbonate CO_3^{-2}
Bi or Hydrogen carbonate HCO_3^{-1} Acetate $C_2H_3O_2^{-1}$ Oxalate $C_2O_4^{-2}$
Silicate SiO_4^{-4} Nitride N^{-3} Nitrate NO_3^{-1} Nitrite NO_2^{-1} Phosphate PO_4^{-3}
Monohydrogen phosphate HPO_4^{-2} Hydrogen phosphite HPO_3^{-2} Phosphide P^{-3}
Dihydrogen phosphate $H_2PO_4^{-1}$ Arsenide As^{-3} Arsenate AsO_4^{-3} Arsenite AsO_3^{-3}
Oxide O^{-2} Peroxide O_2^{-2} Hydroxide OH^{-1} Chromate CrO_4^{-2} Dichromate $Cr_2O_7^{-2}$
Manganate MnO_4^{-2} Permanganate MnO_4^{-1} Sulfide S^{-2} Sulfate SO_4^{-2}
Hydride H^{-1} Fluoride F^{-1} Chloride Cl^{-1} Bromide Br^{-1} Iodide I^{-1}
Perchlorate ClO_4^{-1} Chlorate ClO_3^{-1} Chlorite ClO_2^{-1} Hypochorite ClO^{-1}

APPENDIX B

PRE-ASSIGNMENT QUIZ ON CHEMICAL NOMENCLATURE

Exercise 1

Pre-Assignment Quiz on Chemical Nomenclature

Answer the following questions: (twenty points)

I. Write the correct formula for the following compounds:

1. Copper(I) nitride ____________________
2. Cobalt(III) acetate ____________________
3. Aluminum cyanide ____________________
4. Barium fluoride ____________________
5. Tin(IV) sulfate ____________________
6. Mercury(I) bromide ____________________
7. Cadmium sulfide ____________________
8. Ammonium nitrate ____________________
9. Nickel(II) phosphate ____________________
10. Potassium permanganate ____________________

II. Write the correct Stock Name for the following compounds:

1. SnF_2 ____________________
2. Ag_2SO_4 ____________________
3. $AuAsO_4$ ____________________
4. $NaNO_2$ ____________________
5. KCN ____________________
6. $(NH_4)_3PO_4$ ____________________
7. CrP ____________________
8. $LiIO_4$ ____________________
9. CaC_2O_4 ____________________
10. $MgSO_4$ ____________________

APPENDIX C

POST-ASSIGNMENT QUIZ ON CHEMICAL NOMENCLATURE

Exercise 2

Post-Assignment Quiz on Chemical Nomenclature

Answer the following questions: (twenty points)

I. Write the correct formula for the following compounds:

1. Strontium hydrogen sulfate ______________________
2. Lithium hypochlorite ______________________
3. Aluminum phosphide ______________________
4. Iron(III) acetate ______________________
5. Lead(IV) cyanide ______________________
6. Silver bromate ______________________
7. Magnesium iodite ______________________
8. Calcium carbonate ______________________
9. Cobalt(III) sulfate ______________________
10. Mercury(II) arsenate ______________________

II. Write the correct Stock Name for the following compounds:

1. Rb_2S ______________________
2. $NaIO_3$ ______________________
3. $SnCl_4$ ______________________
4. $Cr_2(CO_3)_3$ ______________________
5. NH_4I ______________________
6. $Pb(NO_2)_2$ ______________________
7. NaClO ______________________
8. $Mg(CN)_2$ ______________________
9. Li_3P ______________________
10. $K_2Cr_2O_7$ ______________________

APPENDIX D

CHEMICAL NOMENCLATURE
STUDY QUESTIONNAIRE

Exercise 3

Chemical Nomenclature Study

Questionnaire

Answer the following questions that apply to your participation in this study.

1. What was it that you liked most about the way you were taught nomenclature? (Please be specific).

2. Was there anything that you did not like about working with the Method that you were using? Be specific, if you have constructive criticism.

3. What would you recommend to improve the effectiveness of the teaching of chemical nomenclature? Give this some serious thought.

4. Do you feel that you have attained a certain amount of mastery of chemical nomenclature by participating in this study? Please elaborate.

APPENDIX E

STOCK METHOD NOMENCLATURE RULES

Stock Method Nomenclature Rules

Rules for Writing Formulas for Ionic Compounds (*59*)

- An ionic compound must contain both cations and anions.
- The formula for the cation is always written before the formula for the anion.
- The total number of positive charges on the cations must equal the total number of negative charges on the anions so that the net charge is zero. This determines the cation-to-anion ratio, hence the subscripts in the formula of the compound

Rules for Predicting the Charge on a Monatomic Ion (*59*)

- The charge on a main-group (A group) metal ion equals the group number of the metal. (Some main-group metals of large atomic number have ions equal to the group number minus two; common examples are Sn^{2+} and Pb^{2+}).
- The charge on a transition-metal ion is not easy to predict, because most of them have two or more ions of different charge. Refer to the oxidation numbers of the transition metals on the periodic table for specific charges.
- The charge on a nonmetal ion equals the group number minus eight (giving it a negative number).

Rules for Naming a Binary Ionic Compound When the Metal Forms a Single Cation (*59*)

- The cation is named for the metallic element from which it is obtained.
- The anion name is derived from the element by retaining the root name and adding the suffix –ide (i.e. chlorine becomes chloride).
- The binary ionic compound is named by giving the name of the cation (omitting the word ion) followed by the name of the anion (again omitting the word ion).

Rules for Naming a Binary Ionic Compound
When the Metal has more than one Charge *(59)*

- Refer to the periodic table to see the possible charges on the cation. (i.e. Fe can be +2 and +3).

- Determine the charge on the corresponding anion and identify its total charge. (i.e. chloride is –1, but count the number of chloride ions to determine its total negative charge).

- The cation charge must balance the anion total charge.

- Denote the cation charge with a Roman numeral when naming the compound. (i.e. $FeCl_3$ is Iron(III) chloride).

APPENDIX F

QUESTIONNAIRE RESPONSES

Questionnaire Responses
(Unedited)

Question No. 1

What was it that you liked most about the way you were taught nomenclature? (Please be specific).

Group I (Traditional) Student Responses:

"I liked the helpfulness of the instructor. Everything was taught very clearly and in a way that I could understand it."

"It was explained simply and my questions were happily answered w/ a reason why. The sheet w/ common ions was extremely useful!"

"I liked that everything was explained in detail; you weren't left to guess or assume anything."

"It was made as simple as possible. I was taught the charges for the different cations and how to name them. The amount of practice in lab helped more than anything."

"I like the emphasis placed upon its importance. I also like the forced repetition."

"I really like the experience in the lab."

"I thought all the exercises we did in lab the one day were extremely helpful."

"I wasn't here for the lab part of it, but I think the rules we were given help me."

"I did not understand nomenclature in class or in lab, but I understand it better after the test help session."

"I liked the lab research because I feel like I got the most that I've ever gotten out of nomenclature in lab."

Group II (Rainbow Wheel) Student Responses:

"The repetition helped a lot, actually. Complete instructions on using the game were provided by the instructor, and he was willing to answer my questions about writing the formulas."

"The color wheel and chart make it easy to learn."

"How to read it off of the periodic table, like whatever family it is in –8 from it to get the number."

"It was interactive instead of reading about it in the book."

"The Rainbow game in lab; it was what taught me how to do it."

"I had already had some knowledge of nomenclature, but I liked how the transition metals' charges with the Roman Numeral naming was explained. Playing the game (wheel) was fun and helped me to practice naming everything. The Rainbow Wheel was effective b/c it was presented like a fun game and it kept my attention better. It wasn't as tedious as the normal lecture and then move on method like my teachers in the past have used. Also, I liked it when examples were given and we were taken step-by-step through the procedure to combine and name them. I learned well with well explained examples. I get to really see how everything is being put together."

"I liked the wheel of nomenclature we did in lab. In lecture I didn't really understand what was being taught to me."

Group III (Rainbow Matrix) Student Responses:

"The fact that I learned how to do nomenclature in one day. The program used on the computer."

"The computer room time. It helped me to visually understand and interact with others as I learned."

"The computer game really helped me to visualize how the compounds are formed. I liked the idea of combining cations and anions on the computer screen. It was a great idea! By repeating the combinations over and over, it really drove the point home and helped me see just how to do chemical nomenclature. I found the game very student friendly."

"I prefer your method using the computer. By using the computer you were able to grab hold of the symbols by using a toll: 'computer' that they were familiar with and enjoyed operating. The game was well designed to A. use the periodic table
B. use ionic compound sheet."

Question No. 2

Was there anything that you did not like about working with the Method that you were using? Be specific, if you have constructive criticism.

Group I (Traditional) Student Responses:

"I did not like the notes we had to write. They were confusing until we actually saw examples, then it all came together and I could make sense of the notes. I think it would be better to provide examples along with the notes. Everything would be great then."

"Doing the problems over and over was a little repetitive, but in the long run, helped drill it into my head. Maybe narrow down the # of problems?"

"No"

"The method used was effective for me; again, practice helped tremendously."

"I felt the introductory notes were not clear."

"The first lecture class was so boring, because I had to write what was on the board, and I couldn't listen to at the same time. The act of writing the answers to the questions at the back of the book was boring and tedious."

"No. I thought everything was very well-organized and educational."

"Not really."

"I was not sure how to do nomenclature, and still now not sure about it. I would prefer to be taught another method."

"I didn't like doing the pre/post quiz because I felt like I hadn't had enough practice since high school and it was a little discouraging."

Group II (Rainbow Wheel) Student Responses:

"The spinning wheel thing seemed a little unnecessary."

"No. I enjoyed the Method."

"No, it worked great!"

"I felt like we were too old to play a game to learn."
"No"

"The Rainbow Wheel was fun, but I think only using 10 different cations and anions to make 100 compounds was tiring, b/c you catch on to the pattern that every cation is paired with the same 10 anions over and over. Maybe if there was more variety to pairing and naming them. For example, use 20 cations to pair with 5 anions to make 100 or vice versa. It's not as repetitious and gives more practice."

"Without our cheat sheet that has all the oxidation numbers, I wouldn't have known what the oxidation numbers were or how to figure them out. I think you should try to explain and be more thorough on how to figure out the oxidation numbers."

Group III (Rainbow Matrix) Student Responses:

"Took too long, but if 100 is the right #, then it will be fine."

"No, I really wish a little bit more of chemistry was taught in the aspect nomenclature was in this experiment."

"No, not really. I liked the computer game."

"The only thing I didn't agree with was the # of question asked to solve. It took too many hours to complete, but if 100 is the magic #, I guess that is what it has to be."

Question No. 3

What would you recommend to improve the effectiveness of the teaching of chemical nomenclature? Give this some serious thought.

Group I (Traditional) Student Responses:

"I would recommend a whole lot more practice: homework problems, quizzes."

"The Roman Numeral ions were most confusing. A deeper discussion of which charge to use would help."

"I thought the method used was very effective and an easy way to understand. I can't think of anything to add."

"More time to learn and grasp the concepts. Even though I did not miss any of the nomenclature material on the tests, 2 days was not enough time spent on the material."

"Do not allow pairing up in the nomenclature game on the computer. More little ten question quizzes help to retain information. Possibly once a month or every other week having a review quiz."

"Make the lecture class more interesting."

"I honestly cannot think of any way to improve it."

"I would suggest making some kind of game or memorization exercise out of it. I think this would make it more interesting and easier to learn and remember."

"I feel we should have done some problems together in class instead of just giving us the notes. We worked some problems in lab, but we should have been exposed to problems during lecture."

"Talk to students more about how a chemical will react and say it over and over again."

Group II (Rainbow Wheel) Student Responses:

"A more effective cation/anion chart would help."

"A little more clarification on ion charges and naming of compounds 'ide' 'ite', etc.

"Make a easy way for it so students will pick it up faster rather than –8 for the family group item. For example, criss-crossing the cosigns (cations and anions) this may make it a whole lot easier to do and remember rather than looking up and finding. Same way goes for the opposite. That's how I did all my problems and found it to be much easier."

"Have the Instructor explain more and give more examples in class. You could give us more of a warning before you through all of it at us at one time."

"When we were taught the nomenclature, I remember thinking how well everything was explained. However, I also remember one thing I would have changed to help improve the effectiveness. The first day when we were lectured to I didn't hear anything b/c I and most of the class were frantically trying to write down the notes on the board. I personally can't pay attention to 2 things at once. I suggest that you just pass out those rules in the 1st place. That way when you lecture we all ready have them to refer to, instead of trying to write them as we listen. It would be more effective for the lecturing if we can look down and refer to something we all ready have."

"Don't use the over head projector. It sounds tedious, but I was too busy trying to get everything copied to even pay attention. Use the board and be more hands on. This is more effective."

Group III (Rainbow Matrix) Student Responses:

"It works, just provide us with more instructions."

"I really think the computer room should be a theory used for a while along with the lecture. It's really excellent."

"I really think the computer was very helpful, but some of us are not computer literate, so it is still challenging to us. Continue to give more examples in class and lab."

"Go over periodic table, show how to get charge #'s of elements. Give at least 10 examples, and show how to use periodic table and ionic compound sheet to solve the problem."

Question No. 4

Do you feel that you have attained a certain amount of mastery of chemical nomenclature by participating in this study? Please elaborate.

Group I (Traditional) Student Responses:

"Yes, because I understand the concept much better than before and I am very comfortable doing nomenclature."

"Yes, I learn best by actually doing examples. I am not an 'oral learner', but hands-on learner. The exercises helped a lot."

"Yes, the lab where we worked various problems out of the text was the most helpful. Being able to apply what had been taught and having the opportunity to ask one-on-one questions and receive detailed explanations to those questions was the best part of this study. It helped me grasp chemistry that I'd forgotten."

"Somewhat, with more practice and continuing to use the method I was taught, should result in a much better understanding of nomenclature."

"I feel that given a periodic table with possible charges of the transition metals, I could identify the majority of chemical compounds."

"The exercise in the lab helped me a lot."

"Yes – I already know a lot of what we learned from high school, so I feel very strong in this particular subject."

"Somewhat, at least I hope I've gotten better at chemical nomenclature."

"No. I learned about nomenclature, but not through participating in the research. I learned the night in the help session."

"Yes; I definitely feel that out of a week I've learned more than a year in high school, and in high school I was in Honors Chemistry and made a B^+ in the course."

Group II (Rainbow Wheel) Student Responses:

"I feel like I know nomenclature better than if hadn't done this method."

"Yes, for I found other ways in doing it. And I also memorized most of the cations and anions. The wheel was very helpful in learning chemical nomenclature."

"Somewhat. I know a little more than I did before."

"A little. I have never done it before and I feel I know a lot about it, but there is more I could learn to do much better at it."

"Yes, like I said I all ready had some knowledge but this study has only helped to improve it and clarify some things for me. I now understand the transition metals' charges (how you know which one to use and how to name them).
Also, the naming of the compounds is easier for me. I had not known before about adding the ide to chlorine, sulfur, etc. I feel confident in my ability to correctly answer any question dealing with nomenclature."

"I have never really worked with nomenclature, so after this I have a much greater understanding. Not mastery, but much more than before."

Group III (Rainbow Matrix) Student Responses:

"Yes, I am confident in chemical nomenclature."

"Yes. I don't believe I would have grasped the concept of this part of chemistry as easily if I had not been able to see it in the computer room as you lectured. I like the fact that one can take the notes and put them into visual form and see what was just spoken."

"After working with the Matrix, I now have a much better understanding of chemical nomenclature. When I was in high school, I never really understood how the formulas were to be written and named, but now it is all clear to me. Other students should try using this computer game. I highly recommend it!"

"I do feel confident in my ability to perform chemical nomenclature largely due to repetition (computer game). The idea of repeating these combinations over and over again causes one to remember the patterns and see this all fits together. It would be great if other topics in chemistry could be taught this way!"

APPENDIX G

LETTER TO STUDENTS REQUESTING CONSENT AND RELEASE FORM

Consent and Release Form

Dear Student:

Presently, I am doing research in chemical education. My research involves comparing the differences and effectiveness of three different methods in learning chemical nomenclature. Your participation in this research will be greatly appreciated.
As a potential participant, you will remain **anonymous** and to participate or not to participate will have no affect on your grade.

Your participation is completely voluntary and should you wish not to participate, that would be ok. But in an effort to improve students' working knowledge of chemical nomenclature, it would be greatly appreciated if you do participate. Plus, you may have a lot of fun in the process. Should you have any questions, please call me at 898-2946. Thank you in advance for your participation.

Sincerely,

Joseph Chimeno

APPENDIX H

CONSENT FORM

Consent Form

By signing this form, I understand that my chemical nomenclature quiz scores will be used as research material. I maintain that I am doing this of my own free will. I also understand that my grade in this class will in no way be affected by my participation in this research.

Confidentiality of my grades and name will be assured, and I reserve the right to withdraw at anytime.

Signature ______________________________________

Printed Name __________________________________

Date ____

APPENDIX I

APPROVAL LETTER FROM MTSU

Middle Tennessee State University
Department of Chemistry
1301 East Main Street
Murfreesboro, TN 37132

To Whom It May Concern:

The MTSU chemistry department hereby grants Joseph S. Chimeno, a doctoral student in our department, permission to conduct educational research with one of our general chemistry classes (CHEM 1110) for the purpose of evaluating chemical education teaching tools. It is understood that this research will involve one general chemistry class for the spring term 2003 and that the students are participating on a voluntary and anonymous basis. Beginning January 2003, research data will be collected within the fall semester. Mr. Chimeno will publish the results of this research as partial fulfillment of his doctoral dissertation at Middle Tennessee State University in Murfreesboro, Tennessee.

Signed this 2nd day of December 2002.

Dr. Earl F. Pearson
Chemistry Department Chair
Middle Tennessee State University
1301 East Main Street
Murfreesboro, TN 37132
Phone (615) 898-2958
Fax (615) 898-5182

APPENDIX J

APPROVAL LETTER FROM NIACC

North Iowa Area Community College
500 College Drive
Mason City, Iowa 50401
1-888-466-4222

To Whom It May Concern:

North Iowa Area Community College hereby grants Joseph S. Chimeno, a chemistry instructor at NIACC, permission to conduct research at our main campus for the purpose of evaluating chemical education teaching tools. It is understood that this research will involve three classes of introductory chemistry students and that the students are participating on a voluntary and anonymous basis. Beginning January 2002, research data will be collected within a one year time period. Mr. Chimeno will publish the results of this research as partial fulfillment of his doctoral dissertation at Middle Tennessee State University in Murfreesboro, Tennessee.

Signed this 2nd day of October 2001.

Dr. Michael C. Morrison
Vice President for Academic Affairs
North Iowa Area Community College
500 College Drive
Mason City, Iowa 50401
Phone: 641-422-4002
Fax: 641-423-1711

APPENDIX K

APPROVAL LETTER FROM THE INSTITUTIONAL REVIEW BOARD

School of Nursing

P.O. Box 81
Middle Tennessee State University
Murfreesboro, Tennessee 37132
(615) 898-2437

MTSU

October 29, 2001

Box 68
Chemistry Department
Middle Tennessee State University
Murfreesboro, TN 37132

Re: "The Assessment of the Rainbow Wheel & Rainbow Matrix Chemical Nomenclature Games"
(IRB Protocol Number: 02-069)

Dear Joseph,

The MTSU Institutional Review Board, or a representative of the IRB, had reviewed your research proposal identified above. It is determined that the study poses minimal risk to subjects and qualifies for an expedited review under 45 CFR 46.110 and 21 CFR 56.110.

Approval is granted for up to 100 subjects based on the number submitted in the protocol.

Final approval is for one (1) year from the date of this letter.

Please note that any change to the protocol must be submitted to the IRB or to your college representative before implementing any change.

Final Approval: October 29, 2001

Best of luck in the successful completion of your research project.

Sincerely,

Karen S Ward

Karen S. Ward, PhD, RN
Member, MTSU Institutional Review Board

Cc: MTSU IRB Committee
Dr. Gary Wulfsberg, Faculty Supervisor

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